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U.S. Army Environmental Center
*Demonstration of Physical Separation/Leaching Methods
for the Remediation of Heavy Metals Contaminated
Soils at Small Arms Ranges
(Acid Leaching Demo)*

8443

Worldwide Search Report

DISTRIBUTION STATEMENT A

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February 7, 1997

Project Identification:

DESA Contract: SEA993-95-C-0007

Subtask: 02-01/00

PID No.: P94-154-001

19980414 179

DTIC QUALITY INSPECTED 8

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U.S. Army Environmental Center

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

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|---|--|---|---|
| 1. AGENCY USE ONLY (Leave blank) | | 2. REPORT DATE February 7, 1997 | 3. REPORT TYPE AND DATES COVERED Technology Demonstration, Nov 1995-Sep 1997 |
| 4. TITLE AND SUBTITLE Demonstration of Physical Separation/Leaching Methods for the Remediation of Heavy Metals Contaminated Soils at Small Arms Ranges (Acid Leaching Demo): Worldwide Search Report | | | 5. FUNDING NUMBERS |
| 6. AUTHOR(S) BDM Engineering Services Company | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) BDM Engineering Services Company 1801 Randolph Road, S.E. Albuquerque, NM 87106 | | | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Environmental Center Aberdeen Proving Ground, MD 21010-5401 | | | 10. SPONSORING / MONITORING AGENCY REPORT NUMBER SFIM-AEC-ET-CR-97048 |
| 11. SUPPLEMENTARY NOTES | | | |
| 12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; distribution is unlimited | | | 12b. DISTRIBUTION CODE |
| 13. ABSTRACT (Maximum 200 words) The U.S. Army Environmental Center in partnership with the Naval Facilities Engineering Services Center and the U.S. Army Engineer Waterways Experiment Station demonstrated Physical Separation/Leaching methods for the remediation of small arms range soils. The demonstration occurred at Fort Polk, Louisiana. After conducting a world-wide search, two vendors were selected to demonstrate two variations of the physical separation/leaching technologies. The first using a process based on acetic (weak) acid chemistry and the second based on hydrochloric (strong) acid chemistry. Following completion of the bench treatability studies, each vendor performed a full scale (5-10 tons per hour, 1000 tons total) demonstration of their respective technologies. This report documents the worldwide search that was performed to identify vendors of soil remediation equipment and/or contractors who have successfully completed similar remediation projects. A number of information sources, including experts at government and R&D institutions, libraries, professional journals, on-line services, academia and industry contacts were used to complete this report. Should the reader be interested in other environmental problems or other technologies not considered for this report, a listing of Internet sites searched during the effort is included and provides ample coverage of the remediation technologies available. The mention of trade names or commercial products in this report should not be constituted as endorsement or recommendation for use. | | | |
| 14. SUBJECT TERMS Soil Washing , Heavy Metals, Recycling, Physical Separation, Small Arms Ranges, Technology Demonstration, Acid Leaching, Lead Remediation, Implementation, Maintenance, TCLP, Bench-Scale test, Screening, Attrition Scrubbing | | | 15. NUMBER OF PAGES 101 |
| | | | 16. PRICE CODE |
| 17. SECURITY CLASSIFICATION OF REPORT Unclassified | 18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified | 19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified | 20. LIMITATION OF ABSTRACT |

INTRODUCTION

This document is the result of investigations into the identifications of currently available, non-biological, technologies that may be applicable for the remediation of lead contaminated soil.

Technologies have been identified that fall into one of 8 broad categories: Acetic Acid based leaching, Other leaching, Soil Washing, Electro- technologies, etc.

It is recognized that an identified technology may overlap or fall into more than one category, but for the purposes of this study, it has been placed in one category or another. The intent is not to determine the appropriateness of the category in which it was placed, but rather to simply account for the candidate technology.

Note: (1) *Mention of trade names or commercial products does not constitute endorsement or recommendation for use.*
(2) *For costs provided, the basis of the cost estimates have not been evaluated. For each application, cost factors for process and cost elements such as capital costs, operation and maintenance, life-cycle, administrative, and cost of money should be considered.*

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BACKGROUND

Numerous DoD installations have sites which contain soil that contain heavy metals as a result of use for small arms training. Primary methods for the remediation of these sites involves solidification, stabilization and/or landfilling. These methods minimize hazards due to contaminant migration and exposure to humans and the environment, but the contamination and the liability for it remain. In addition, processes such as stabilization significantly increase the volume of the final waste form. Processes are needed which are cost competitive with the stabilization/landfilling processes and result in removal of the heavy metal contaminants as well as providing substantial net waste volume reduction. The principal objective of this subtask is to conduct a technology demonstration to investigate the technical and economic applicability of two physical separation / leaching processes for the removal of heavy metals from the soil at Fort Polk LA, while providing substantial overall net waste volume reduction.

Soil washing extracts contaminants from excavated soil by mixing the soil with water, solvents, surfactants, or chelating agents (Schwinkendorf and others, 1995). Soil washing is a combination of physical and chemical treatments performed on soil in an aqueous solution. Soil size segregation is often accomplished by washing the fines from coarse soil. As a result of segregation the process removes contaminants that reside in specific grain-size domains, separates the waste stream into "cuts", and focuses on treatment appropriate to the contaminant / grain-size relationship. Usually, heavily contaminated soils are treated several times in a multistage counter-current system. Contaminated water or solutions generated during the soil washing process is treated for removal of contaminants.

A basic soil washing treatment system includes four major sub-systems: 1) screening (soil preparation), 2) washing, 3) soil and water separation, and 4) waste water and sludge treatment and management (Mann 1992a, EPA 1993a, EPA 1994). Screening is employed to remove the oversized soil fraction. The initial process is done by vibrating screens and then by attrition scrubbers. Water is then added, and the resulting slurry is separated into coarse-grained sands and fine-grained materials, typically by use of hydrocyclones. Underflow from the hydrocyclones contain the coarse-grained sands which require treatment, typically by air froth flotation. Surfactants may be added to the sand to aid in reducing the surface tension binding the contaminant to the particles (West and Harwell, 1992). This allows the contaminants to "float". They are then removed by flotation and forwarded onto sludge management. Overflow from the hydrocyclones contains the fine-grained contaminated material. This fraction can then be either processed by an alternative technology, or dewatered and disposed of off site. The small volume of contaminated metal residuals are subsequently recycled or treated by appropriate immobilizing processes such as solidification, or vitrification. Sludge management typically requires additional treatment such as polymer addition, thickening, and dewatering. Cleaned soil may be either redeposited on-site or otherwise beneficially used as backfill or industrial sand. Process water is generally cleaned of contaminants and recycled for further use in the system. (Dickerson and others, 1995a)

Variations of soil washing technology include; debris washing, solvent washing, solvent extraction and in-situ soil flushing. A brief description is given below.

DEBRIS WASHING

As defined by EPA, debris is a solid material exceeding 60-mm particle size that is intended for disposal and that is 1) a manufactured object; 2) plant or animal matter or 3) natural geologic material. Debris washing technology is grossly similar to that of soil washing, but typically includes additional steps for screening, mixing, and scrubbing, as well as variations within similar stages. Debris washing technologies include: water or solvent washing, chemical foams and gels, acid or caustic washing, liquid-phase solvent extraction and vapor-phase solvent extraction.

SOLVENT EXTRACTION

Solvent extraction is potentially effective in treating contaminants by separation of contaminants into three fractions: oil, water, and solids. Solvent extraction technology generally involves three stages: soil washing using a solvent, soil drying and solvent regeneration (FRTR, 1991).

Contaminated soils, slurries or waste waters are first fed into the extractor. The extraction fluid (solvent) is circulated through the contaminated matrix to wash the soil. Liquified gas solvent may be used to extract organic compounds, oil, and grease from contaminated soils and sludges. Typically, more than 99% of the organic compounds are separated from the feed. Following phase separation of the solvent and organic constituents, treated water is removed from the extractor, while the mixture of solvent and organic constituents passes to the separator through a valve where pressure is partially reduced. In the separator, the solvent is vaporized and recycled as fresh solvent. The organic compounds are drawn off from the separator and either reused or disposed. Hot inert gas or solvent-free gas is heated and injected into the soil to complete its drying (Dickerson and others, 1995a).

INPUT AND OUTPUT STREAM CHARACTERISTICS

Ex-Situ soil washing is applicable to soil, sediments and sludges contaminated with hazardous organic compounds, radionuclides, and toxic heavy metals. Specifically the process can be applicable for treatment of soils contaminated with wood-preserving chemicals (e.g., PCP, creosote), organic solvents, electroplating residues (e.g., cyanides, heavy metals), paint sludges, pesticides, and petroleum and oil residues (EPA, 1991). Particle size distribution is a key parameter in determining the feasibility of soil washing. Typically for soil washing to be economical, the contaminated material size distribution should not consist of more than 40% passing 45 microns or 325 mesh (EPA, 1994). Materials finer than this begin to reduce the amount of recovered clean soil for redeposition. In addition, the contaminated soil should contain less than 20% by volume of solid organic material such as leaves, roots, and twigs. In situ soil washing (flushing) is most applicable to highly permeable soils. All input streams must be sorted, separated, and prepared prior to soil washing (DOE, 1991).

There are four waste streams generated during soil washing: 1) contaminated fines and humic compounds from the soil washing unit; 2) waste water; 3) sludge from soil washers, and; 4) air emissions (16). Soil washing is typically considered a waste minimization, volume reduction process which reduces the original amount of material that needs to be remediated by an ultimate destruction or immobilization technology. Thus, solid output soil washing streams can be further separated into two broad categories: 1) coarse-grained cleaned material for on-site backfilling and redeposition and 2) fine-grained material requiring further treatment for regulated disposal (1). Discharge water may need treatment to meet discharge standards; however, this water should be recovered and reused to the maximum extent possible in the washing process. The residual solids from the waste water treatment process, such as spent carbon and sludges, must be treated prior to disposal. Air emissions must be monitored and treated to meet regulatory standards.

TECHNOLOGY STATUS

Soil washing is a readily available technology that has been used as a remedial action for contaminated soils. Several soil washing demonstrations have been conducted by the EPA at Superfund sites. In addition, soil washing is a widely utilized remedial action in many European countries. Several full-scale soil washing plants with capacities of 6 to 30 tons/h are in operation in the Netherlands and Germany (Gerber and others, 1991). Soil (165 tons) from the United States have been shipped to the full-scale facility at Mocrdijk, the Netherlands, for testing (Mann and Opet, 1992). This plant has an annual treatment capacity of 80,000 tons. However, emphasis in Europe is on removal of semivolatile organic compounds, polyaromatic hydrocarbons, PCBs, and pesticides.

REMOVAL EFFICIENCY

Based on individual site characteristics, removal efficiencies are reported anywhere from 85 to 99% for organic compounds, 80 to 99% for semivolatile organic compounds, 50 to 99% for oil and grease (and other petroleum hydrocarbons), 84 to 88% for PCBs, 93 to 99% for cyanides, and 50 to 90+% for heavy metals (EPA, 1991, 1994). As a very general statement, applicable contaminants can usually be removed from coarse soil fractions (greater than 200 mesh) with relatively high removal efficiencies (95 to 99.9%) at low to moderate cost, while fine soils, silts, and clays (<200mesh) yield only moderate contaminant removal efficiencies (50 to 90%) at moderate to high costs (EPA, 1994). Volatile organic contaminants are easily removed from soil with a 90 to 99% efficiency. Semivolatile organic contaminants may be removed to a lesser extent with use of a surfactant (40 to 90%), while metals and pesticides, which are less soluble in water, often require acids or chelating agents for removal (EPA, 1991).

COSTS

The following are EPA comments on soil washing (Dickerson and others, 1995a; EPA, 1991): 1) Treatment and disposal of contaminated residuals can be a major expense; 2) design field tests can be expected to range from as low as \$100,000 to more than \$500,000 (1989 costs); 3) costs for German (Harbauer GmbH) full-scale soil washing facility are reported as, capital costs \$6,000,000 (1986 dollars) for a 15 to 20 ton/h facility, O&M costs of \$150/ton soil including water treatment, sludge disposal costs of \$50/ton of treated soil, and 4) processing costs for other less complex European soil washing operations are estimated at \$73 to \$100/ton soil.

SUMMARY AND REQUIRED DEVELOPMENT

The primary advantage of soil washing is volume reduction of wastes requiring ultimate disposition. Soil washing can be cost-effective as a pre-processing step in reducing the quantity of material to be recycled processed by another destruction and/or immobilization technology. It may also be used to transform the feed into a more homogeneous condition to augment subsequent treatment systems operations. Additionally, soil washing provides a closed system that remains unaffected by external conditions, and hazardous wastes can be excavated and treated on-site (EPA, 1992).

Contaminants in soils containing a high fraction of silt and clay-sized particles are, typically, strongly absorbed and are difficult to remove by soil washing. Hydrophobic contaminants generally require surfactants or organic solvents for removal from the soil, while complex contaminant mixtures in soils, as well as frequent changes in the contaminant compositions, make it difficult to design a single washing fluid that will consistently and reliably remove all of the contaminants (EPA, 1991).

A major need in development of soil washing is a clear understanding of the acceptable cleanup concentrations of contaminants. The nature of the extraction medium depends on characteristics of the organic compound, radionuclide, and/or heavy metal in the soil and the physiochemical characteristics of the soil; thus each contaminant and soil needs to be investigated to properly assess the probability of decontamination. Simple soil washing, using water as the extraction medium, will not suffice in cleanup of heavy-textured soils containing a variety of radionuclides, heavy metals, and organic contaminants (Dickerson and others, 1995a).

Each soil washing vendor uses a slightly varied process train and/or reagents for removal of contaminants. For example, addition of catalytic ozone oxidation of the wash water to destroy organic compounds (EPA, 1993b). Brief descriptions of the processes (i.e. vendors), the removal efficiency and costs, are presented. This information is based largely on data gathered through our worldwide search.

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PURPOSE OF THE WORLDWIDE SEARCH

Problem

DoD installations have sites with soil that contains heavy metals, primarily lead, as a result of use for small arms training. The currently accepted method for the remediation of these sites involves contaminant solidification, stabilization, and/or landfilling. While this method minimizes hazards due to contaminant migration and exposure to humans and the environment, the contamination and the liability for it remain.

Mission Statement

Contaminant separation technologies are sought and evaluated in this study that have the capability to remove the contaminant of interest (Pb) without destroying the organic viability of the soil. For the purposes of conducting the demonstrations during the time frame allotted for this study, priority was given to physical separation / leaching technologies.

Objective

A worldwide search was performed to identify suppliers of soil remediation equipment and / or contractors who have successfully completed similar remediation projects. It is planned to apply two (2) such processes for the separation of lead (Pb) and associated heavy metals (primarily zinc, copper), achieving a volume reduction by rendering the majority of the soil non-toxic (clean) and producing a metal concentrate to be recycled. One of the leaching technologies will be specifically based on acetic acid chemistry.

Product

This study provides documentation of a wide variety of soil separation technologies that are currently available in a way that both technical promoters and lay-persons can recognize the application or lack of application to the specific problem.

Search Parameters

A worldwide search was performed to identify suppliers of soil remediation technologies. A number of information sources, including experts at government and R&D institutions, libraries, professional journals, on-line services, academia and industry contacts were used to complete this task.

Search Locations

Given the exponential growth of information available on-line a majority of the worldwide search was conducted via the Internet. Domestic and international servers were accessed and searched in an effort to provide as complete coverage of the market as possible. A listing of Internet sites searched is provided below. Should the reader be interested in other environmental problems or other technologies not considered for this report, these sites will provide ample coverage of the remediation technologies available.

TABLE OF WORLD WIDE WEB / INTERNET LOCATIONS AND ADDRESSES USED IN THE WORLDWIDE SEARCH

(all location addresses are preceded by http:)

| NAME | LOCATION |
|--|---|
| Australian Department of the Environment | //kaos.erin.gov.au/portfolio/portfolio.html |
| ERIN Environmental Resources Information Network (AUST) | //kaos.erin.gov.au/erin.html |
| ERC Earth Resources Center | //www.clearlake.ibm.com:8001/olqs |
| Ecotech Europe '95 | //qqq.com/ecotech/index.html |
| TNO Netherlands Organization for Applied Scientific Research | //www.tno.nl/ |
| Institute for Environmental Science, Energy Research and Process Innovation (TNO, Netherlands) | //www.tno.nl/instit/mep.html |
| Environmental News Network | //www.env.com |
| GENIE Global Environmental Network for Information Exchange (UK) | //www-genie.mrrl.lut.ac.uk/ |
| The Arkive (Australia) | //www.next.com.au/arkive/index.html |
| HOLIT Israel Ecological and Environmental Information System | //www1.huji.ac.il/ |
| UNEP United Nations Environmental Program | //www.unep.ch |
| Department of the Navy Environmental Program | //enviro.navy.mil |
| USEPA | //iridium.nttc.edu/env/env_eпа.html |
| ENVIRO\$ENSE (EPA) | //wastenot.intel.gov:80/enviro\$en\$e/ |
| Federal Information Exchange | //web.fie.com/web/fed/ |
| Environmental Information (N.Ireland) | //boris.qub.ac.uk/cvni/info.html |
| NEIRC National Environmental Information Resource Center | //www.gwu.edu/~greenu/ |
| NTTC National Technology Transfer Center | //iridium.nttc.edu/nttc.html |
| INDUSTRY NET | //www.industry.net/ |
| ARCS Assessment & Remediation of Contaminated Sediments | //epaserver.ciesin.org/gkreis/glnpo/data/arcs/epa-905-b94-003/epa |
| Technology Reinvestment Program | //www.trp.arpa.mil/trp |
| ARPA Advanced Research Program Agency | //www.arpa.mil/ |
| CIESIN Consortium for International Earth Science Information Network | //www.ciesin.org/ |
| Global Network for Environmental Technology | //www.gnet.org/ |
| USDoD | //iridium.nttc.edu/env/env_dod.html |
| SERDP | //iridium.nttc.edu/env/env_serdp.html |
| Environmental Security Technology Certification Program | //iridium.nttc.edu/env/dod/ddestcp1.txt |
| DOE Environmental Technology Program | //iridium.nttc.edu/env/env_doe.html |
| NASA Environmental Technology Programs | //iridium.nttc.edu/env/env_nasa.html |
| GETE Global Environmental Technology Enterprise | //iridium.nttc.edu/env/general/gete.txt |
| EPA SITE Program | //iridium.nttc.edu/site.html |
| Center for Environmental Enterprise | //www.biddeford.con:80/~camber/env_home.html |
| Center for Clean Technology | //cct.seas.ucla.edu/ |
| Envirolink | //www.envirolink.org/index.html |
| Envirogate | //www.nttc.edu.enviromental.html |

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| | |
|--|--|
| US Bureau of Mines | //www.usbm.gov |
| CEDAR Central European Environmental Data Request Facility | //www.cedar.univie.ac.at/ |
| DOD Environmental Restoration Electronic Bulletin Board | //www.dtic.dla.mil/envirodod/envirodod.html |
| National Environmental Research Council (UK) | //www.nerc.ac.uk/ |

This table should not be considered as a complete listing of environmental sites available on the World Wide Web but as a starting point that will allow the reader / user to obtain a sampling of the wide array of information available. From inside many of the listed sites, the reader may jump off to additional sites where information on topic from 'Green' anything to the latest environmental policy and technologies is available.

LISTING OF TECHNOLOGY VENDORS

1.0 ACID LEACHING

1.1 ACCEL INDUSTRIAL and MINERAL PROCESSES LTD.

Trade Name: The Enviro-Clean Process

TECHNOLOGY DESCRIPTION:

The Enviro-Clean process uses conventional mineral processing equipment to prepare the feed for leaching. The individual processing units will reflect the nature of the host material. Removing metals from contaminated surface water should require limited processing. However, screening, gravity separation and/or flotation may be required before remediating soils. After preprocessing is completed, contaminant metals are solubilized with a leachant optimized for the target contaminant. Each site may require different processes, but in the current process, soil will be separated using conventional technologies (e.g. belt filter or gravity separator). The pregnant liquid is then transferred to a proprietary adsorption column operated in counter current mode. Metals are transferred from the pulped soil leach to an electrowin solution via resin beads. The resin beads have been developed to operate effectively from solutions containing low levels of metals. Effective operation requires rapid loading and stripping cycles and an extended bead life. Leachant is cycled between the leaching tank and loading column. Electrowinning of the strip liquor to recover metals is the preferred option but it is anticipated that a number of other commercially proven techniques may be applied to metal recovery. After leaching, the soil pulp is dewatered by a belt filter and may then be used as a neutral pH fill material. Barren leach liquor having no metal values or other toxic elements may be stored on site for recycling, or discharged as appropriate.

STATUS:

The Enviro Clean soil remediation process has been successfully demonstrated on a pilot-scale system. The contaminated soil used was from a site at Homebush Bay in Sydney, New South Wales, Australia. The small scale continuous flow counter current pilot plant was constructed and operated by CSIRO Melbourne in accordance with Accel designs and instructions. The feed stock was heavily contaminated with lead, chrome and cadmium and had lesser levels of zinc. Remediation of the soil was attained to such a degree that the treated soil would have no restrictions on its use under guidelines for both European/Dutch and US EPA standards.

Sample sizes of the soil treated ranged from 1 to 2 kg. Extended testing on samples up to 10kg were also carried out. The process has not been fully optimized, therefore detailed costings and definitive results over a range of soils cannot be made at the present time. The cost of the EnviroClean process appears, at this stage of development, to be competitive with other remediation processes.

1.2 ADI/TALLON

TECHNOLOGY DESCRIPTION:

Tallon Metal Technologies Inc. has developed a method for the recovery of heavy metals from wastewater and from heavy metal wastes from the mining industry. The technology is an integration of materials handling procedures as employed in the minerals processing industry and as adapted to soil treatment by Tallon with the hydrometallurgical and other physico-chemical recovery techniques which Tallon had developed for selective recovery of heavy metals and organic contaminants from soil and other wastes. This technology was applied at the Dickson remediation project, Bombardier, Inc., in Montreal, Quebec, Canada where characterization studies revealed elevated levels of lead, copper and arsenic. After excavation, contaminated soil is screened for oversized material and metallic debris is magnetically removed. The remaining material is then washed directly into double-cell attrition scrubbers and then discharged through a

magnetic purifier. The nonmagnetic material is then discharged to a spiral classifier where coarse and fine fractions are separated, with the fines going to a flotation cell. Here the heavy metal enriched float is collected, dewatered and prepared for disposal.

Process water met discharge limits for disposal into the local sewer system while the treated soil exhibited a significant reduction in metals to below regulatory criteria.

STATUS:

Tallon Environmental, Inc. currently manages the largest heavy metal contaminated soil remediation project in North America at the Canadian Forces Base Longue Pointe in Montreal. This operation involves an 800 tons per day soil processing / recycle plant with the goal of processing over 160,000 tons of soil.

1.3 CENTER FOR HAZARDOUS MATERIALS RESEARCH

TECHNOLOGY DESCRIPTION:

The acid extraction treatment system (AETS) uses hydrochloric acid to extract heavy metal contaminants from soils. Following treatment, the clean soil may be returned to the site or used as fill. First, soils are screened to remove coarse solids. These solids, typically greater than 4 millimeters in size, are relatively clean and require at most a simple rinse with water or detergent to remove smaller attached particles. After coarse particle removal, the remaining soil is scrubbed in an attrition scrubber to break up agglomerates and cleanse surfaces. Hydrochloric acid is then introduced into the soil in the extraction unit. The residence time in the unit varies depending on the soil type, contaminants, and contaminant concentrations, but generally ranges between 10 and 40 minutes. The soil-extractant mixture is continuously pumped out of the mixing tank, and the soil and extractant are separated using hydrocyclones. When extraction is complete, the solids are transferred to the rinse system. The soils are rinsed with water to remove entrained acid and metals. The extraction solution and rinsewaters are regenerated using a proprietary technology that removes the metals and reforms the acid. The heavy metals are concentrated in a form potentially suitable for recovery. During the final step, the soils are mixed with lime and fertilizer to neutralize any residual acid. No wastewater streams are generated by the process.

WASTE APPLICABILITY:

The main application of AETS is extraction of heavy metals from soils. The system has been tested using a variety of soils, containing one or more of the following: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The treatment capacity is expected to range up to 30 tons per hour. AETS can treat all soil fractions, including fines. The major residuals from AETS treatment include the cleaned soil, which is suitable for fill or for return to the site, and the heavy metal concentrate. Depending on the concentration of heavy metals, the mixtures of heavy metals found at the site, and the presence of other compounds (calcium, sodium) with the metals, heavy metals may be reclaimed from the concentrate.

STATUS:

Under the Emerging Technology Program, laboratory-scale and bench-scale tests were conducted to develop the AETS technology. The bench-scale pilot system was constructed to process between 20 and 100 kilograms of soil per hour. Five soils were tested, including an EPA synthetic soil matrix (SSM), and soils from four Superfund sites, including NL Industries in Pedricktown, New Jersey; King of Prussia site in Winslow Township, New Jersey; a smelter site in Butte, Montana; and Palmerton Zinc site in Palmerton, Pennsylvania. These soils contained elevated concentrations of some or all of the following: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The table below summarizes soil treatability results based on the EPA Resource

Conservation and Recovery Act (RCRA) hazardous waste requirements for toxicity characteristic leaching procedure (TCLP) and the California standards for total metal concentrations. Detailed results from the study have been published by EPA in a Final Report (EPA/540/R-94/513) and a Summary (EPA/540/SR-94/513).

TECHNOLOGY HIGHLIGHTS:

AETS has been tested on five soils containing a total of seven heavy metal contaminants: As, Cd, Cr, Cu, Ni, Pb, and Zn. The soils have included soils from four Superfund sites and the EPA prepared SSM soil. The system has been shown to be effective for all metals and in all soils, except for lead in the SSM soil, in removing heavy metals to below both TCLP and applicable total metal standards (California TTLP standards). Removal efficiencies for total metals have ranged up to 95 percent. Reduction efficiencies for TCLP have ranged up to 99 percent.

One of the key advantages of AETS over other systems is its ability to remove heavy metals from all fractions of the soil. It is not akin to some "soils washing" systems in which the primary process technology is based on particle size separation. It has been tested and shown to work on all fractions of the soil tested, including the fines.

The results of the study are summarized below:

AETS can treat a wide range of soils containing a wide range of heavy metals to reduce the TCLP below the RCRA limit. AETS can also reduce the total metals concentrations below the California mandated total metals limitations. In most cases, AETS can treat the entire soil, without separate stabilization and disposal for fines or clay particles, to the required TCLP and total metal limits. The only exception was the SSM, which may require separate stabilization and disposal of 20 percent of the soil to reduce the total TCLP lead concentrations appropriately. However, AETS successfully treated arsenic, cadmium, chromium, copper, nickel, and zinc in the soil. Treatment costs under expected process conditions range from \$100 to \$180 per cubic yard of soil, depending on the site size, soil types and contaminant concentrations. Operating costs ranged from \$50 to \$80 per cubic yard. These costs are competitive with alternative technologies.

TECHNOLOGY LIMITATIONS:

The system is not recommended for materials containing over 80,000 ppm heavy metals contamination. Above that range, other pyrometallurgical removal techniques may be more efficient and economical. AETS has not been tested in applications which involve both heavy metal and organic contamination, although there is no reason to believe that it cannot be combined with organic removal techniques (surfactant washes) to create a joint system.

1.4 COGNIS, INC.

TECHNOLOGY DESCRIPTION:

The COGNIS, Inc. (COGNIS), TERRAMET soil remediation system leaches and recovers lead and other metals from contaminated soil, dust, sludge, or sediment. The system uses a proprietary aqueous leachant that is optimized through treatability tests for the soil and the target contaminant. The TERRAMET system can treat most types of lead contamination, including metallic lead and lead salts and oxides. The lead compounds are often tightly bound by fine soil constituents such as clay, manganese and iron oxides, and humus. A pretreatment, physical processing stage may involve dry screening to remove gross oversize material. The soil can be separated by particle size into oversize (gravel), sand, and fine (silt, clay, and humus) fractions. The oversize fraction is usually clean after the surfaces are scrubbed through attrition. Lead is invariably found in the fines fraction, and this fraction is subjected to counter-current leaching to dissolve the adsorbed lead and other heavy metal species. The sand fraction may also contain significant lead, especially if the contamination is due to particulate lead, such as battery

recycling, ammunition burning, and scrap yard activities. In this case, the sand fraction is pretreated to remove dense metallic or magnetic materials before subjecting the sand fraction to counter-current leaching. Sand and fines can be treated in separate parallel streams. After dissolution of the lead and other heavy metal contaminants, the metal ions are recovered from the aqueous leachate by a metal recovery process such as reduction, liquid ion exchange, resin ion exchange, or precipitation. The metal recovery technique depends on the metals to be recovered and the leachant employed. In most cases, a proprietary reduction process is used so that the metals are recovered in a compact form suitable for recycling. This method is very effective for lead, copper, and mercury, among others. After the metals are recovered, the leachant can be reused within the TERRAMET plant for continued leaching. Important characteristics of the TERRAMET leaching/recovery combination are as follows:

The leachant is tailored to the substrate and the contaminant.

The leachant is fully recycled within the treatment plant.

Treated soil can be returned on-site.

All soil fractions can be treated.

WASTE APPLICABILITY:

The COGNIS TERRAMET metal leaching system can treat soil, sediment, and sludge contaminated by lead and other heavy metals or metal mixtures. Appropriate sites include contaminated ammunition testing areas, firing ranges, battery recycling centers, scrap yards, metal plating shops, and chemical manufacturers. The system can treat metallic lead as well as lead salts and oxides. Certain lead compounds, such as lead sulfide, are not amenable to treatment because of their exceedingly low solubilities. The system can be modified to leach and recover other metals, such as cadmium, zinc, copper, and mercury, from soils. End products include clean soil and recycled metal. No wastewater is generated during processing. Water is disposed only upon completion of the job; after neutralization and clarification within the plant, it meets pretreatment standards for municipal wastewater treatment plants.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in August 1992. Based on results from the Emerging Technology Program, the technology was accepted into the Demonstration Program in 1994. The demonstration took place at the Twin Cities Army Ammunition Plant (TCAAP) Site F during August 1994. The system was evaluated during a full-scale remediation conducted by COGNIS at TCAAP. The TERRAMET process treated soil contaminated by lead and copper at levels up to 3,000 parts per million, and lesser amounts of antimony, cadmium, chromium, mercury, nickel, and silver. The system treated soil at a rate of 10 to 20 tons per hour. Detailed results from the demonstration will be available in 1995.

To date, lead-contaminated soil samples at concentrations of 17,000 parts per million (ppm) have been treated to less than 300 ppm residual lead. The system has also removed metals to below background concentrations; for example, from greater than 400 ppm lead to less than 8 ppm lead.

1.5 EARTH DECONTAMINATORS, INC. (EDI)

Trade Name: Metals Leaching

TECHNOLOGY DESCRIPTION:

This technology involves soil washing for the leaching of hazardous metals from soils in a non-acidic, proprietary solution. After mixing the proprietary leaching solution with the soil, solids are separated from the washing liquid. Metals are then precipitated from the liquid. The liquid is regenerated and sent back to the beginning of the leaching process. The metals are concentrated (40 percent) and are sold to a smelter. The soil is backfilled on site. The chemicals employed in the washing process are nonhazardous, do not volatilize, and do not require input of thermal energy. Levels of decontamination are dependent on regulatory requirements. Process time

depends on the soil type and a combination of the metals and their concentrations. Average costs range from \$100 to \$150 per ton.

TECHNOLOGY HIGHLIGHTS:

Remediation works can be performed on various soils, including loam, clay, and sand. One or a combination of metals may be leached using the neutral pH solution (patent pending) that is non-hazardous. No fumes or sludges are generated, and input of thermal energy is not required. Operations occur at ambient temperature. Once leached, the metals are participated from the catalyst and collected at about 40 percent concentration. Metals can be removed to concentrations below the soluble regulatory limits (STLC). Clean soil can be left on site.

TECHNOLOGY LIMITATIONS:

This process works most effectively on oxidized metals. It does not work effectively on elemental metals. This technology will be effective when hydrocarbons are present at concentrations below 1,000 ppm and it can be used as a second step in combination with hydrocarbon remediation. The pH should be close to neutral and can be adjusted before remediating. This process will remediate antimony, arsenic, barium, beryllium, cadmium, chromium VI and III, cobalt, copper, fluoride salts, lead, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc.

OTHER COMMENTS ON TECHNOLOGY:

Remediation has been completed for treatment of runoff water containing arsenic. Contamination was reduced to below 1 ppm. Demonstration has been performed for process water remediation containing 35 ppb of chromium VI. The concentration was reduced to below 1 ppb. Process equipment can treat 12 tons per hour of contaminated soil.

1.6 EARTH TREATMENT TECHNOLOGIES, INC.

Trade Name: Metals Recovery and Recycling System

TECHNOLOGY DESCRIPTION:

The process is unique in that (1) regulated metal contaminants are selectively extracted while non-regulated metals remain in the treated soil, (2) metal contaminants are discharged from the process as a 50% to 99% pure concentrate suitable for and consistent with regulatory requirements for recycling and (3) all soil fractions are remediated on site; therefore no importing of backfill soil and no off-site management of any soil fraction is necessary.

The process is semicontinuous and consists of three key treatment steps: physical separation, chemical extraction and liquids processing.

In the physical separation step; the excavated, contaminated soil is segregated into the various fractions, particulate metal contaminants are removed and those soil fractions which require further treatment are identified.

The chemical extraction step is a multistage solvent extraction which utilizes proprietary additives in an acidic solvent so as to preferentially remove metal contaminants while leaving non-regulated, naturally occurring metals in the soil. The optimal solvent/additives formulation, the required number of stages and the key operating parameters are site specific and are determined by performing bench-scale treatability studies.

In the liquids processing step, the metal laden solvent is treated by filtration and electro-chemical processes to selectively recover the metal contaminants in a concentrated form suitable for recycling to commercial smelters. The solvent is treated and recycled back to the chemical extraction portion of the process.

TECHNOLOGY HIGHLIGHTS:

To date, the technology has successfully remediated soils contaminated with mercury, lead, chromium, cadmium, copper, nickel, and zinc.

The cost of full scale treatment using the metals recovery and recycling system is site specific and varies based on the soil characteristics, the concentration and chemical state of the targeted metal contaminants, the concentration of non-targeted metals and the required cleanup objectives. The cost is generally less than the cost of landfill disposal, soil washing or soil stabilization.

The key benefits of this technology when compared to the other three alternatives are that the generator's long term liability is terminated, there is no need to import backfill soil and the metals are recovered in a highly concentrated form suitable for recycling.

An increasing number of states are regulating the total metal content of the treated soil in addition to the federally mandated soluble metal content. Consequently, stabilization is no longer technically viable in those states. However, the metals recovery and recycling system reduces the total metal content of the treated soil to well below those concentrations being set by these state regulations.

TECHNOLOGY LIMITATIONS:

The technology is designed to remediate soils which are contaminated with regulated metals. The presence of non-friable porous material, organic compounds, and non-regulated metals are of significant concern when applying this process. None of these three aspects make the application of the system impossible. However, they may increase the cost.

OTHER COMMENTS ON TECHNOLOGY:

The metals recovery and recycling system is recognized as a recycling technology as defined by RCRA regulations. State approvals to operate the system under recycling exemptions have been obtained.

1.7 IT CORPORATION

Trade Name: Batch Steam Distillation/Metals Extraction

TECHNOLOGY DESCRIPTION:

The batch steam distillation/metal extraction treatment process is a two-stage process to remove organics and heavy metals from contaminated soils. The first stage, steam stripping, removes volatile organics from a slurry of the contaminated soil by direct steam injection. The volatile organics are taken overhead, condensed, cooled and collected.

For treatment of metals, steam stripping is followed by acid extraction. The soil slurry is washed with hydrochloric acid. Subsequent countercurrent batch washing with water removes residual acid from the soils. The solids are then separated from the final wash solution by gravimetric sedimentation. The acid extract stream is then routed to a batch distillation system for the recovery of excess hydrochloric acid and heavy metals. The treated soils can be returned to the site.

TECHNOLOGY HIGHLIGHTS:

Two types of soil contaminants most commonly found at Superfund sites are volatile organic compounds and heavy metals, and they frequently occur together. Existing technologies for treating soils do not deal with both of these contaminants; they treat either one or the other. This

two-stage technology provides a simple, cost-effective method for removing these contaminants from soil.

The advantages of this two-stage process are:

- Equipment is simple,
- Process is not affected by soil moisture content,
- Process adjustments are easy to implement for changes in soil characteristics,
- Scale up is direct and uncomplicated,
- Air emissions are minimized and easily controlled, and
- Excess reagents can be easily recovered.

TECHNOLOGY LIMITATIONS:

The process as currently designed is a batch process. This limits the process capacity of the system and directs its application to smaller hazardous waste sites.

Certain waste contaminants can cause foaming of the slurried soil during the batch steam distillation step. Anti-foaming agents or reduced steam rates can control this phenomenon.

OTHER COMMENTS ON TECHNOLOGY:

This technology is part of a treatment train system; treatment of organics is listed under Thermal Desorption. Additional technology information is available from IT Corporation on a case-by-case basis.

IT's Batch Steam Distillation/Metals Extraction technology has been successfully demonstrated at pilot-scale and awaits an opportunity for full-scale implementation.

1.8 LEWIS ENVIRONMENTAL SERVICES, INC./HICKSON CORPORATION

(Chromated copper arsenate soil leaching process)

TECHNOLOGY DESCRIPTION:

Lewis Environmental Services, Inc. (Lewis), has developed a soil leaching process to remediate soils contaminated with heavy metals including chromium, copper, cadmium, mercury, arsenic, and lead. This process can treat soils contaminated with inorganics, some organics, heavy metal hydroxide sludges, and sediments. The soil leaching process consists of leaching contaminated soil in a countercurrent stirred reactor system. A screw feeder delivers the soil into the reactor, where it is leached with sulfuric acid for 30 to 60 minutes. The sulfuric acid solubilizes the inorganics and heavy metals into the leaching solution. The processed soil is then separated and washed with water and air dried. Any organic contaminants are separated and decanted from the leaching acid, using strong acid leachate, space separation, and skimming. The wash water is then treated with Lewis' ENVIRO-CLEAN process, which consists of a granulated activated carbon system followed by an electrolytic recovery system. The ENVIRO-CLEAN process recovers the heavy metals from the leaching stream and wash water and produces an effluent that meets EPA discharge limits for heavy metals. The treated wash water can then be reused in the soil washing step. The leaching solution can also be treated by the ENVIRO-CLEAN process or can be returned directly to the stirred reactor system, depending on its metals concentration. Contaminated soil must be properly sized and screened to facilitate leaching in the stirred reactor system. Large pieces of debris such as rocks, wood, and bricks must be removed before treatment. Standard screening and classification equipment, such as that used in municipal waste treatment plants, is suitable for this purpose. The soil leaching process does not generate appreciable quantities of treatment by-products or waste streams containing heavy metals. The treated soil meets toxicity characteristic leaching procedure (TCLP) criteria, and can be returned

to the site or disposed of at a nonhazardous landfill. The granular activated carbon requires disposal after about 20 to 30 treatment cycles and should also pass TCLP criteria, simplifying disposal.

WASTE APPLICABILITY:

The soil leaching process can treat solid wastes generated by the wood preserving and metal plating industries, battery waste sites, and urban lead sites. The advantages of this process over traditional waste treatment schemes for chromated copper arsenate (CCA) wastes are as follows: Treated soils pass TCLP criteria and can be reapplied on site. Treatment by-products do not require disposal as hazardous waste. Land disposal of large volumes of soil is eliminated. Heavy metals are recovered by the ENVIRO-CLEAN process and can be reused by industry.

STATUS:

The Soil Leaching Process was accepted into the Emerging Technology Program in 1993. Laboratory-scale tests have shown that the process successfully treats soil contaminated with CCA. In 1992, Lewis treated a 5-gallon sample of CCA-contaminated soil from Hickson Corporation (Hickson), a major CCA chemical manufacturer. The treated soil passed TCLP criteria, with chromium and arsenic, the two main leach constituents, averaging 0.8 milligrams per kilogram (mg/kg) and 0.9 mg/kg, respectively. Analysis also revealed 3,330 milligrams per liter (mg/L) of chromium, 13,300 mg/L of copper, and 22,990 mg/L of iron in the leaching solution. In addition, analysis indicated 41.4 mg/L of chromium, 94.8 mg/L of copper, and 3.0 mg/L of arsenic present in the wash water. After treatment, the wash water contained metals levels below 0.1 mg/L for copper and chromium. Lewis plans further laboratory-scale testing at its Pittsburgh, Pennsylvania facility, followed by bench- or pilot-scale testing at Hickson's facility in Conley, Georgia.

1.9 LOCKHEED CORPORATION

TECHNOLOGY DESCRIPTION:

Lockheed offers a variety of remediation systems tailored to the client's need and is continually developing new techniques for characterization and remediation of wastes. The approach used for a given contamination problem is site specific.

In many cases of contamination, the material requires treatment with a suitable acidic media in order to remove the contaminant of concern. The selection of the appropriate solvent for use and the conditions of the leaching are again site specific. The selection of the approach and the accompanying leach conditions necessary are key to the development of the most economic solution to the particular problem.

Lockheed has successfully designed, constructed and operated batch and continuous treatment facilities. The choice of the mode of operation typically is dependent upon the amount of material to be processed but that decision can be influenced by the process utilized.

The use of the technology involves the solubilization of the constituents of concern followed by the isolation of the various soluble elements into appropriate forms. The goal of the treatment is to minimize the volume of the hazardous/radioactive constituents for ultimate disposal.

The process utilizes physical separation techniques (if appropriate) to isolate the fractions of concern in minimal volumes. The contaminant is then removed from the contamination fractions using the acid extraction techniques discussed above.

TECHNOLOGY HIGHLIGHTS:

The process utilizes physical separation techniques if appropriate to isolate the fractions of concern in minimal volumes. The contaminant is further removed by acidic treatment when it is found to be effective. This operation can be concurrent or counter current as conditions dictate. The soluble element/elements of concern are further isolated using other hydrometallurgical techniques appropriate to the situation.

The treatment of a given contaminated material will usually involve the following operations:

Physical Segregation; Size reduction; Leaching; Liquid Solid Separation (if necessary); Soluble Contaminant isolation (precipitation, IX, SX, etc., as necessary); and Dewatering and Water Treatment

TECHNOLOGY LIMITATIONS:

The use of all metallurgical techniques can be limited by the nature of the contamination. In cases where the contaminant is distributed within the entire matrix of the soil, gravity separation and similar physical separation techniques are not applicable for the preliminary isolation of the contaminated fraction. In some cases, the use of hydrometallurgical techniques may prove to be appropriate for the entire contaminated material. If the contaminant is both distributed and not amenable to economic hydrometallurgical methods, the treatability with volume reduction as the goal may prove to be unachievable. In such an instance, Lockheed immobilization techniques may prove to be appropriate.

OTHER COMMENTS ON TECHNOLOGY:

Full scale processes have been employed successfully to remediate depleted uranium, and uranium process residues. Other systems have been designed for treatment of natural uranium contaminated materials.

Processes for the treatment of materials containing multiple heavy metals have been devised and successfully demonstrated. Facilities for the treatment of those materials have been changed and construction and operation of those plants is anticipated.

Typical Projects:

China Lake Naval Air Weapons Center and The Idaho National Engineering Laboratory Pit 9

Lockheed has also treated wastes from battery, recycling disposal, chloro-alkali manufacturing, electroplating, metal ore mining and smelting, petroleum refinery, inorganic chemical manufacturing, semiconductor manufacturing, rubber manufacturing and landfill sites. Lockheed has performed remediation at RCRA, CERCLA, TSCA, DOD, DOE, and state sites. Projects have ranged from bench scale to treatability studies to full scale.

2.0 SOIL WASHING TECHNOLOGIES

2.1 AEA TECHNOLOGY

NATIONAL ENVIRONMENTAL TECHNOLOGY CENTRE
(formerly WARREN SPRING LABORATORY)

TECHNOLOGY DESCRIPTION:

The National Environmental Technology Centre of AEA Technology is investigating potential mineral processing techniques for soil separation and washing. The process can be used 1) as a stand alone volume reduction process where contaminated products are disposed of in landfills; or 2) as a pretreatment technology before secondary treatment or disposal. The process is based on mineral processing equipment. The process combines equipment for size fractionation, density separation, and froth flotation. The exact combination and sequence of equipment depends on the nature of the specific material to be treated and contaminant distribution. Material content and contaminant distribution are determined by customized laboratory characterization procedures. A typical operation involves wet screening at 50 millimeters (mm) with high pressure water jets. Material measuring less than 50 mm enters a washing mill containing a scrubbing medium. The mill overflow is screened at 1 mm, again under a water jet. Material measuring 1 to 50 mm is further screened at 10 mm. Material measuring less than 1 mm enters a hydrocyclone operating to separate at approximately 10 micrometers (μm). The fraction measuring 10 μm to less than 1 μm is partially dewatered using a spiral classifier prior to a separation stage based on the combined parameters of size and density. A hydrosizer, or alternatively a spiral, can be used for this process. The siliceous coarse product from the hydrosizer is de-watered and stockpiled without further treatment. The medium product from the hydrosizer is screened at 500 μm prior to entering a magnetic separator, while the fine/light product is hydrocycloned prior to entering the magnetic separator. Following magnetic separation, the material enters one or more froth flotation stages, or alternatively a gravity separation stage using a multigravity separator. These stages produce a contaminant concentrate and leave the remaining material relatively contaminant free.

WASTE APPLICABILITY:

The technology is being developed to remove metals, petroleum hydrocarbons, and poly-nuclear aromatic hydrocarbons from soil. Sediments and certain industrial wastes such as sludges may also be candidates for treatment. The soil selected for a pilot-scale operation is from a gasworks; other applications include soils from petrochemical plants, pickling plants, industrial chemical plants, coke manufacturers, iron and steel manufacturing plants and foundries.

TECHNOLOGY HIGHLIGHTS:

The technology discussed provides range of techniques and options for treatment of contaminated land. Based on physical processing principles, it should have advantages over the existing processes, including chemical and pyrometallurgical treatments. It has the potential to produce a small contaminated product and a large decontaminated product for clean end-use. The final treatment of the contaminants (biological, chemical, incineration, solidification, etc.) could therefore be carried out more cheaply and efficiently, providing an integrated system for Superfund sites. All the processes available are capable of treating hundreds of tons per hour at a commercial scale.

TECHNOLOGY LIMITATIONS:

The technology is an ex situ process and therefore could be more expensive than an in situ process. Contaminants are not destroyed or rendered nontoxic. They are concentrated prior to treatment by another process. It is a slurry-based system and water supply and recycle are inherent to the process. Some damage also may occur to soil structure.

OTHER COMMENTS ON TECHNOLOGY:

The technology is established throughout the mining industry, and its applicability to soil treatment has now been confirmed. Limited application of these techniques is already practiced in Europe and AEA Technology has successfully applied some of the techniques at pilot scale to different types of contaminated soil.

STATUS:

The technology was accepted into the SITE Emerging Technology Program in July 1991. The project consisted of the initial characterization in the laboratory of contaminated soils from three different locations. One soil, from a gasworks, was then selected for a pilot-scale operation using a circuit designed to exploit differences in contamination distribution identified in the soil during the laboratory characterization. The pilot-scale operation was conducted on about 30 tons of soil at a throughput of about 0.5-1 ton per hour. Several test runs were conducted to permit a comparison of the effectiveness of different equipment combinations.

2.2 ALTERNATIVE REMEDIAL TECHNOLOGIES, INC.

TECHNOLOGY DESCRIPTION:

Soil washing is a physical/chemical process to remove contaminants that reside in specific grain-size domains. It is a batch process and separates the wastestream into "cuts" and focuses on treatment appropriate to the contaminant/grain-size relationship.

The Process:

Prior to treatment, oversize materials are separated from the contaminated soil with a series of vibrating screens. Wet screening is then applied to form a slurry which is pumped to the hydrocyclones. The hydrocyclones mechanically separate the slurry into two streams, the underflow and the overflow. The underflow, which contains the coarse-grained material, is directed to the froth flotation cells where it is washed with surfactants. The flotation cells are mechanically aerated and the combined effects of aeration and surfactant washing generate a heavy froth that floats to the top of the cells. The overflow (the fines and water) is treated like an industrial effluent. The waste stream is directed to a sludge basin where solids are allowed to settle. The resulting sludge is dewatered using a belt filter press and may then be further treated or disposed.

TECHNOLOGY HIGHLIGHTS:

The advantages of using the Alternative Remedial Technologies, Inc. (ART) soil washing system, over more conventional cleanup methods are many. The system is exceptionally cost-effective since treatment is focused on the contaminated fraction only, thus minimizing the volume of material to be disposed of off-site. Of the total volume of feed material, only 5-8 percent will require disposal at a treatment, storage, and disposal facility. Typically, approximately 85 percent of the feed material can be returned to the site as clean. It is a true volume reduction option and directly supports the recycle and reuse of site materials.

A wide spectrum of contaminants can be treated with this soil washing system, including semivolatile organics including polynuclear aromatics (PNA), pesticides, polychlorinated biphenyls (PCB), chlorinated hydrocarbons, and inorganics such as heavy metals, cyanides, and radioactively contaminated materials. The system can effectively treat both organics and inorganics in the same treatment process.

The system is modular and transportable and can be set up on a site in two weeks. Only water and electricity are required. There is no effluent water to be treated as all water is recycled to the wet scrubber. The plant is relatively easy to operate, and its flexibility is such that it needs not be

kept running 24 hours per day, as is the case with an incinerator, for example. If required, the plant can operate on a 7 days per week/24 hours per day schedule.

TECHNOLOGY LIMITATIONS:

This method of treatment is most economically effective on soils that are no more than 30 percent clay or silt. As the proportion of the fine-grained material increases, the wastestream becomes more difficult to process, which adds to the cost. Full-scale soil washing is competitive with other remediation technologies on projects that require cleanup more than 20,000 tons. Smaller volumes of soil can be processed with ARTs 5-10 tons per hour pilot plant.

Volatile organics will normally be removed prior to introduction of the soil into the treatment unit.

OTHER COMMENTS ON TECHNOLOGY:

In 1992, the firms of Geraghty & Miller, Inc. (USA) and Heidemij Realisatie (The Netherlands) formed a joint venture and were incorporated as Alternative Remedial Technologies, Inc. (ART) to bring the Heidemij soil washing system to the U.S.

Heidemij is an environmental consulting, management, and remediation firm over 100 years old and the market leader in The Netherlands in soil washing. ART performed the first full-scale cleanup using the soil washing technology in the U.S. at the King of Prussia Technical Corporation Superfund site in Winslow Township, NJ. Soil washing operations were completed in October 1993 with 19,200 tons of soil being remediated. ART also performed pilot scale soil washing at the Department of Energy Hanford Site on uranium contaminated soils in 1994. ART has performed treatability studies on soils contaminated with PCBs, VOCs, mercury, lead, pesticides, TPH, PAH, PNA, arsenic, and chromium. Permitting is not usually required for field operations.

2.3 BENCHEM

TECHNOLOGY DESCRIPTION:

BenCHEM has developed an aqueous, ambient temperature and pressure process to scrub heavy metals from soil. Although one reagent is a weak acid solution, all the other reagents are more gentle and biodegradable.

The portable process is a multi-stage elutriation system in which contaminated soils flow counter-current to the soil washing agents. There are typically 4 to 5 stages in the elutriation system. Once through the system the solubilized/suspended metals are sorbed to an active carbon substrate. An electric current is applied to desorb the metals from the adsorption substrate. The electrical desorption recovers a raw form of each metal which is transported to a metals refining facility.

The soil is continuously washed and all elutriant streams are closed loops. When the soil exits, it is innocuous and can be returned on site.

TECHNOLOGY HIGHLIGHTS:

To date, excellent results have been achieved with leaching and recovery of chromium and mercury from contaminated soils. TCLP leaching tests on the cleaned soil have exceeded specifications.

From design flow schematics, it is anticipated that the first portable test plant will continuously process 50 tons of soil per hour.

Performing financial analysis indicated that the total processing costs should be less than or at least competitive with landfilling soils contaminated with heavy metals.

TECHNOLOGY LIMITATIONS:

The process may require some screening and crushing to achieve particle sizes of 1/8 inch or less. Other preprocessing and preparation steps may be necessary depending on the particular metals and soils at the site.

The best results are achieved with inorganic mining ores and ore processing tailing wastes. Some organics can also be scrubbed from the soil using the aqueous medium. Provisions are made to dispose of these minor quantities of organic wastes. However, high molecular weight metal organics are more difficult to remove.

OTHER COMMENTS ON TECHNOLOGY:

BenCHEM has been incorporated for approximately 1 year. The technology evolved from a coal cleaning process used to removed sulfur from coal. In doing this, it was discovered that metals in the coal were also being removed.

The technology has been applied to petroleum contaminated soils containing tetraethyl lead. Results indicate that the soils passed TCLP for lead.

2.4 BERGMANN USA

TECHNOLOGY DESCRIPTION:

Soil/sediment washing is a water-based, volumetric reduction/waste minimization process whereby hazardous contaminants are extracted and concentrated into a small residual portion of the original volume using physical and chemical methods. Cleaned soil may be either redeposited on site or otherwise beneficially used as backfill or industrial sand. The small volume of contaminated residuals are subsequently treated by appropriate destructive or immobilizing processes such as incineration, thermal desorption, chemical extraction, biodegradation, solidification, or vitrification.

The techniques and unit operations employed in soil/sediment washing are largely transferred from the mineral processing field. Depending on the site characteristics, the physical separation techniques utilized may include crushing, screening, hydraulic classification, attrition scrubbing, dense media separation, heavy media concentration, gravity concentration, froth flotation, dissolved air flotation, and mechanical dewatering.

Associated chemical aids may include surfactants, chelating agents, coagulants, flocculants, and pH modifiers, etc.

TECHNOLOGY HIGHLIGHTS:

Soil/sediment washing is an effective treatment method for both land based soils as well as river bottom and harbor sediments. The key phrase to associate with soil washing is "waste minimization". Soil and sediment washing can make an important contribution to waste minimization when used as a pretreatment to other destructive or immobilizing processes. Normally the process permits concentration of hazardous contaminants into a residual product representing only 10 percent to 30 percent of the original volume. The remaining fraction (70 percent to 90 percent) of decontaminated soil may be redeposited on site or used in some other beneficial manner.

Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, polychlorinated biphenyl (PCB), polynuclear aromatic hydrocarbons (PNA), pentachlorophenol (PCP), cyanides, and pesticides.

Bergmann USA designs and manufactures transportable equipment modules which can be readily mobilized and demobilized on site. Modules are pre-piped and pre-wired with quick interconnections. A Bergmann process engineer and lead technician provide technical assistance for on-site plant erection, commissioning, and training to the remedial contractor or client during plant commissioning.

TECHNOLOGY LIMITATIONS:

Soil/sediment washing is not a "magic black box" which either destroys or effectively changes contaminants. It is a waste minimization/volume reduction process which reduces the original amount of material that needs to be remediated by an ultimate destruction or immobilization technology. In general, for soil washing to be economical, the contaminated material size distribution should not consist of more than 40 percent passing 45 microns or 325 mesh. Materials finer than this begin to reduce the amount of recovered clean soil for redeposition. In addition, the contaminated soil should contain less than 20 percent by volume of solid organic material such as leaves, roots, and twigs. Potential sites should have a minimum of 5,000 tons of material in order to justify the fixed costs of mobilization and demobilization.

OTHER COMMENTS ON TECHNOLOGY:

Bergmann USA and Bergmann N.V. of Holland are member companies of the worldwide Harrisons & Crosfield Group, headquartered in London. Bergmann Holland is the world's leading company in the field of soil and sediment washing technology, having supplied thirty full-scale, commercial installations ranging from 5 to 350 tons per hour (TPH).

Bergmann USA has been established as the soil washing technology center for all North American projects. Our staff includes engineers and specialists in the mining, mineral processing, and environmental remediation disciplines.

Projects in North America have included:

- 1) A 10 TPH demonstration plant for the Toronto Harbour Commissioners (evaluated under the EPA SITE Program - EPA/540/AR-93/517);
- 2) A 10 TPH barge mounted plant for removal of PCB contaminants from dredged sediments for the U.S. Army Corps of Engineers. This project was conducted in conjunction with the U.S. Army Corps of Engineers and Remediation of Contaminated Sediments (ARCS) program and the U.S. EPA SITE program. Preliminary results indicate a 91 percent reduction of PCB contamination in the clean sand fraction;
- 3) A 250 kg/day mobile pilot-batch soil/sediment washing system was fabricated specifically for Rust Remedial Services (formerly Chem-Waste Management - Nuclear Remediation Division) for utilization on radioactive contaminated materials;
- 4) A 10 TPH plant was engineered and fabricated for Canonie Environmental Service in the remediation of lead battery contaminated soils occurring at a Superfund Site in Region 10;
- 5) Key 12 TPH soil washing modules have been provided to EcoTek in the remediation of radioactive contaminated soils occurring at nuclear fuel enrichment facility in Erwin, TN.

- 6) DMS - 4 Hydrosizer module for incorporation with the USEPA/USDOE's 5 TPH pilot soil washing plant for radioactive contaminated materials - delivered to Bechtel National, Oak Ridge, TN;
- 7) A 5 TPH pilot soil washing system to Metcalf and Eddy for operations at the Arsenic and lead contaminated sites in Dupont, WA and Bridgeport, CT;
- 8) An 850 GPM (50 TPH) system to Conti Environmental for dewatering of chromium contaminated hydraulic dredge spoils and recovery of \$200/ton bentonite slurry at the Allied Signal Baltimore Harbor Superfund Project.

2.5 BIOGENESIS ENTERPRISES, INC.

TECHNOLOGY DESCRIPTION:

The BioGenesis processes use specialized, patent pending equipment, complex surfactants, and water to clean soil, sediment, and sludge contaminated with organic and inorganic constituents. Two types of mobile equipment wash different sizes of soil particles. A truck-mounted batch unit, processing 40 yards per hour, washes soil particles 10 mesh and larger. A full-scale, mobile, continuous flow unit cleans sand, silt, clay, and sludge particles smaller than 10 mesh at a rate of 20 to 80 yards per hour. Auxiliary equipment includes tanks, dewatering and water treatment equipment, and a bioreactor. Extraction efficiencies, per wash cycle, range from 85 to 99 percent. High contaminant levels require multiple washes. The principal components of the process include pretreatment equipment for particle sizing, a truck-mounted soil washer for larger particles, a sediment washing unit(s) for fine particles, and water treatment and reconditioning equipment. The BioGenesis soil washing system for larger particles consists of a trailer-mounted gondola plumbed for air mixing, water/chemical addition, oil skimming, and liquid drainage. Water, BioGenesis cleaning chemicals, and soil are loaded into the gondola. Aeration nozzles feed compressed air to create a fluidized bed. The resulting slurry is agitated to release organic and inorganic contaminants from the soil particles. After mixing, a short settling period allows the soil particles to sink and the removed oil to rise to the water surface where it is skimmed for reclamation or disposal. Following drainage of the wash water, the clean soil is evacuated by raising the unit's dump mechanism. Processed soil contains a moisture level of 10 to 20 percent depending on the soil matrix.

A prototype BioGenesis sediment washing machine was tested in Environment Canada's Contaminated Sediment Treatment Technology Program. The sediment washing machine is a continuous flow unit. Capacities of up to 80 to 100 cubic yards per hour are possible using full-scale, parallel processing equipment. Sediment is pretreated to form a slurry. The slurry passes to a shaker screen separator that sizes particles into two streams. Material greater than 1 millimeter (mm) in diameter is diverted to the large particle soil washer. Material 1 mm and smaller continues to the sediment washer's feed hopper. From there the slurry is injected to the sediment cleaning chamber to loosen the bonds between the pollutant and the particle. After the cleaning chamber, the slurry flows to the scrubber to further weaken the bonds between contaminants and particles. After the scrubber, the slurry passes through a buffer tank, where large particles separate by gravity. The slurry then flows through hydrocyclone banks to separate solids down to 3 to 5 microns in size. The free liquid routes to a centrifuge for final solid-liquid separation. All solids go to the clean soil pile; all liquid is routed to wastewater treatment to remove organic and inorganic contaminants. Decontaminated water is recycled back through the process. The BioGenesis cleaning chemical is a light alkaline mixture of ionic and non-ionic surfactants and bioremediating agents that act similarly to a biosurfactant. The proprietary cleaner contains no hazardous ingredients and its characteristics were reviewed during the EPA SITE demonstration.

WASTE APPLICABILITY:

This technology extracts many inorganics, volatile and nonvolatile hydrocarbons, chlorinated hydrocarbons, pesticides, polychlorinated biphenyls, polynuclear aromatic hydrocarbons, and most organics from nearly every soil type, including clay.

STATUS:

The BioGenesis soil washing technology was accepted into the SITE Demonstration Program in June 1990. The process was demonstrated at a refinery site in Minnesota. Results from the demonstration have been published in the Innovative Technology Evaluation Report (EPA/540/R-93/510) and the SITE Technology Capsule (EPA/540/SR-93/510). The reports are available from EPA. The BioGenesis sediment washing technology is scheduled for PCB testing under the SITE Demonstration Program in November 1994.

2.6 BIOTROL, INC.

Trade Name: BioTrol Soil Washing System

TECHNOLOGY DESCRIPTION:

The BioTrol Soil Washing System is a patented, water-based volume reduction process used to treat excavated soil. The system may be applied to contaminants concentrated in the fine-size soil fraction (silt, clay, and soil organic matter) or contamination associated with the coarse (sand and gravel) soil fraction. As a part of the process, debris is removed from the soil, and the soil is mixed with water and subjected to various unit operations common to the mineral processing industry. These operations can include mixing trammels, pug mills, vibrating screens, froth flotation cells, attrition scrubbing machines, hydrocyclones, screw classifiers, and various dewatering operations. The core of the process is a multistage, counter-current, intensive scrubbing circuit with inter-stage classification. The scrubbing action disintegrates soil aggregates, freeing contaminated fine particles from the coarser material. In addition, surficial contamination is removed from the coarse fraction by the abrasive scouring action of the particles themselves. Contaminants may also be solubilized, as dictated by solubility characteristics or partition coefficients. Contaminated residual products can be treated by other methods. Process water is normally recycled after biological or physical treatment. Contaminated fines may be disposed of off site, incinerated, stabilized, and biologically treated.

WASTE APPLICABILITY:

This system was initially developed to clean soils contaminated with wood preserving wastes, such as polynuclear aromatic hydrocarbons (PAH) and pentachlorophenol (PCP). The system may also apply to soils contaminated with petroleum hydrocarbons, pesticides, polychlorinated biphenyls (PCB), various industrial chemicals, and metals.

STATUS:

The soil washing system was demonstrated under the SITE Program between September and October 1989 at the MacGillis and Gibbs Superfund site in New Brighton, Minnesota. A pilot-scale unit with a treatment capacity of 500 pounds per hour operated 24 hours per day during the demonstration. Feed for the first phase of the demonstration (2 days) consisted of soil contaminated with 130 parts per million (ppm) PCP and 247 ppm total PAHs; feed for the second phase (7 days) consisted of soil containing 680 ppm PCP and 404 ppm total PAHs. Contaminated soil washing process water was treated biologically in a fixed-film reactor and recycled. A portion of the contaminated soil washing fines was treated biologically in a three-stage, pilot-scale EIMCO Biolift reactor system supplied by the EIMCO Process Equipment Company.

The Applications Analysis Report (EPA/540/A5-91/003) has been published. The Technology Evaluation Report is available from National Technical Information Service (Volume I Order No. PB92-115 310 VI, Volume II Order No. PB92-115 328-V2-PtA, and PB92-115 336-V2-PtB).

DEMONSTRATION RESULTS:

Key findings from the BioTrol demonstration are summarized below:

Feed soil (dry weight basis) was successfully separated into 83 percent washed soil, 10 percent woody residues, and 7 percent fines. The washed soil retained about 10 percent of the feed soil contamination; 90 percent of this contamination was contained within the woody residues, fines, and process wastes. The soil washer removed up to 89 percent PCP and 88 percent total PAHs, based on the difference between concentration levels in the contaminated (wet) feed soil and the washed soil. The system degraded up to 94 percent PCP in the process water during soil washing. PAH removal could not be determined because of low influent concentrations. Cost of a commercial-scale soil washing system, assuming use of all three technologies, was estimated to be \$168 per ton. Incineration of woody material accounts for 76 percent of the cost.

TECHNOLOGY LIMITATIONS:

Usually limited to cases where the fraction of soil particles finer than 38 microns (-400 mesh) represents less than 20-30 percent of the total weight of contaminated soil. It is a cost-effective volume reduction technology that will reduce the amount of residuals that may require further more expensive treatment or disposal.

2.7 BRICE ENVIRONMENTAL SERVICES CORPORATION (BESCORP)

TECHNOLOGY DESCRIPTION:

The Brice Environmental Services Corporation (BESCORP) soil washing plant is a portable, cost-effective, aboveground process that reduces the overall contaminated soil volume requiring treatment. BESCORP's soil washing process involves site-specific unit operations, the selection of which depends on soil and contaminant characteristics, cleanup standards, cost, and client specifications. Soil washing in its most economic applications uses a volume reduction process, in which clean oversize soil is produced by intensive scrubbing, followed by density, magnetic, and size separations. During the volume reduction process, fine contaminants that exist as discrete or attrited particles are partitioned with the soil fines, while the process water is recirculated and treated to remove suspended and dissolved contaminants. BESCORP's small volume reduction plant, used for demonstration and pilot-testing, is contained on one trailer and has a variable process rate from 4 to 20 tons per hour, depending on soil and contaminant characteristics. A full-scale plant has operated successfully since 1993, averaging 600 tons per week during summer 1994 field activities.

WASTE APPLICABILITY:

The BESCORP technology can treat soils contaminated with radioactive and heavy metals. BESCORP has also built a soil washing plant to remediate hydrocarbon-contaminated soil.

STATUS:

The BESCORP soil washing plant was accepted into the SITE Demonstration Program in winter 1991. Under the program, the BESCORP system was demonstrated in late summer 1992 on lead-contaminated soil at the Alaskan Battery Enterprises (ABE) Superfund site in Fairbanks, Alaska. Results from the demonstration are available from EPA in the Demonstration Bulletin (EPA/540/MR-93/503). The Applications Analysis Report and Technology Evaluation Report will be available in late 1994. Soil washing also works as part of a process train with chemical treatment for complete soil remediation. BESCORP's volume reduction and discrete metal recovery process is linked with an acid extraction process developed by COGNIS, Inc., to remove heavy metals from contaminated soil at the Twin Cities Army Ammunition Plant (TCAAP) in New Brighton, Minnesota. Site F, located within the four square mile TCAAP site, was originally an ordnance burning and burial area. The site is part of the Army's \$370 million

Installation Restoration Program, and is undergoing remediation through TCAAP's Resource Conservation and Recovery Act (RCRA) permit.

At Site F, BESCOP and COGNIS, Inc., are treating lead, copper, and several other heavy metals to RCRA cleanup criteria. The technology is treating feed soils containing lead in concentrations from 3,000 to 10,000 parts per million (ppm) to under 300 ppm in a continuous 12- to 15-ton-per-hour process. The 5-trailer, full-scale soil washing system began processing 340 tons of excavated and stockpiled material at Site F in September 1993. Cleanup goals were met, and processing continued until freezing temperatures halted cleanup until spring 1994. Operations began again in May 1994 and continued until October. The scope of work increased with the discovery of additional disposal areas at Site F, increasing the quantity of soil requiring treatment from 7,500 tons to approximately 13,000 tons. Heavy metals recovered from both the soil washing density recovery process and chemical treatment process are sent to a smelter for recycling.

DEMONSTRATION RESULTS:

The SITE demonstration of the ABE site consisted of three test runs, averaging 5 hours in duration; 48 tons of soil were processed. Excavated soil differed greatly from the treatability test soils; as a result, the BESCOP system needed extensive modifications. Preliminary results from the demonstration include the following: Feed soils averaged 4,500 ppm lead and the processed, separated fines fraction averaged 13,000 ppm lead. The system's on-line reliability was 92 percent.

Lead removal from the combined gravel and sand fractions during the three runs were 61, 93, and 85 percent. Large quantities of metallic lead discovered in the excavated soil made it necessary to modify the system. The processed sand and gravel in Run 3 contained no metallic lead. Gravel produced by all three runs met toxicity characteristic leaching procedure (TCLP) criteria, with average lead concentrations in the TCLP leachate at 1.0, 0.8, and 0.2 milligrams per liter. Battery casings removal efficiencies during the three runs were 94, 100, and 90 percent.

2.8 CANONIE ENVIRONMENTAL SERVICES CORP.

TECHNOLOGY DESCRIPTION:

Soil washing is a process of mixing contaminated soil with water ex-situ and mechanically scrubbing and separating the soil fractions to remove the contaminants. Soil washing can be, and has been, used as a single-stage, stand-alone technology where applicable, or coupled with other on-site remediation technologies to achieve desired final contaminant levels or destruction. Many soil contaminants, both organic and inorganic, tend to chemically or physically attach to the silt and clay fractions of the soil. The silt and clay, in turn, tend to attach to coarser sand and gravel particles. The various processes used in soil washing break the silt and clay away from the coarser fractions and scrub the coarser fractions, resulting in clean sand. The initial breakdown process is done by vibrating screens and then by attrition scrubbers. This clean sand can usually be backfilled on site. The fine fraction which contains the contaminants can then either be processed by an alternative technology or dewatered and disposed of off site. Process water is cleaned of contaminants and recycled for further use in the system.

TECHNOLOGY HIGHLIGHTS:

Sec. 121(b) of CERCLA mandates the EPA to select remedies that "utilize permanent solutions and alternative treatment technologies, or resource recovery technologies, to the maximum extent practicable," and "to prefer remedial actions in which treatment permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances." Soil washing accomplishes all of the above where applicable and is steadily gaining favor with the EPA.

Volume reduction of contaminated material is dramatic, and expensive off-site disposal or destruction is minimized. Costs are relatively low because of high processing rates (10-50 tons per hour). Because of high production rates, relatively quick site remediation is possible.

Soil washing can be custom designed as a pre-treatment to obtain optimum results on other downstream technologies. Example: Using soil washing to reduce volume, size and dewater feed for SoilTech's ATP, Canonic's LTTA, incineration, or stabilization.

TECHNOLOGY LIMITATIONS:

Specific removal efficiencies are dependent upon the type and form of a contaminant as well as the type and grain size distribution of the contaminated soil.

As a very general statement, applicable contaminants can usually be removed from coarse soil fractions (greater than 200 mesh) with relatively high removal efficiencies (95.0 to 99.9 percent) at low to moderate cost, while fine soils, silts and clays (less than 200 mesh) achieve only moderate contaminant removal efficiencies (50.0 to 90.0 percent) at a moderate to high cost. Sand fractions can often be cleaned to less than 1 ppm final contaminant concentrations, while silt/clay fractions may only be cleaned to less than 50 ppm. Organic fractions will often not be treatable without additional chemical treatment such as addition of surfactants or ion exchange.

Soil washing systems are usually not technology-limited, but may not be cost effective for difficult to remove or low contaminant levels (less than .5 ppm).

OTHER COMMENTS ON TECHNOLOGY:

Project:

Status:

1. Salt removal system for Petroleum
Environmental Research Foundation.

In progress

2. Bench-scale treatability - removal of thorium and
plutonium from soil for Dept. of Energy

In progress

3. Gould Superfund site - battery waste and lead
contaminated soil.

Pilot complete
Full-scale design in progress

4. Tonalli Battery Superfund Site Proof of Process
for RI/FS.

In progress

5. Pesticide removal for W.R. Grace bench-scale
treatability.

In progress

6. Pesticide removal for confidential client

In progress

7. PCP and carcinogenic PAH removal for confidential client

In progress

2.9 ENSR CONSULTING AND ENGINEERING

TECHNOLOGY DESCRIPTION:

NuKEM Development has developed a soil cleaning process designed to remove hydrocarbons from contaminated soils. Although aqueous soil washing was originally used as the first step in this process, we now believe that in many cases it may be the only treatment necessary to

successfully remediate a contaminated soil. Consequently, NuKEM Development is now offering aqueous soil washing as a stand alone technology.

Aqueous soil washing generally consists of some combination of the following unit operations: screening, sizing, scrubbing, density separation, flotation, flocculation and thickening. Process variables such as pH, temperature and addition of surfactants can also play an important role in removing the contaminants. NuKEM Development believes that the key to the successful application of aqueous soil washing is the understanding that each soil is unique; therefore, a treatability study is extremely important in designing the optimum treatment system.

In a soil washing system, the soil is first screened to remove oversize material and then classified to produce a coarse and fine fraction. The coarse material is scrubbed to remove contaminants (sometimes surfactants are added) and any fine particles adhering to the coarse particles. The cleaned coarse material is dewatered and can be returned to the site as backfill. The fines from both steps are dewatered and sent to off-site disposal or treatment.

The advantage of soil washing is the large volume reduction. Often only 10 to 30 percent of the original soil volume requires disposal. Process water is recycled. Therefore, water treatment is minimal.

TECHNOLOGY HIGHLIGHTS:

Aqueous soil washing can be used to remove both metals and most hydrocarbons from the coarse particles found in soils and sludges. Products from this process are a clean soil fraction that can be returned to the site as backfill and a contaminated soil fraction that is sent for off-site disposal. Water is recycled to the process.

The main advantages of this process are removal of both metals and hydrocarbon contaminants and 60 to 90 percent reduction of the amount of material that has to be disposed.

Soil washing operates at ambient pressures and temperatures less than 110 degrees Fahrenheit and uses equipment that has been proven reliable by years of service in the sand and gravel and mining industries. Removal efficiencies are very soil dependent, but typically ranges from 60 to 90 percent for metals and 90 to 98 percent for hydrocarbons.

The process plant can be designed as mobile or fixed site operation with capacities ranging from 5 tons per hour to unlimited. Treatment costs range from \$70 to \$300 per ton with the main variable being the size of site to be treated. The basic technology is well known and has been used for a number of years in Europe but is just now starting to be used in the United States.

TECHNOLOGY LIMITATIONS:

Aqueous soil washing does not extract contaminants, but it simply transfers them from the coarse particles to the fine particles. Consequently, for each soil there is a relationship between the treatment cost, the disposal cost and the ratio of coarse particles to fine particles at which soil washing is more economical than complete disposal.

The process cannot handle viscous materials such as tars or separate contaminants if they have the same size and specific gravity as the soil particles.

OTHER COMMENTS ON TECHNOLOGY:

Aqueous soil washing has been successfully demonstrated on a number of full-scale plants in Europe. Most of this work has been done on hydrocarbon contaminants, but some metal contaminated soils have also been treated.

NuKEM has conducted bench-scale studies on soils contaminated with hydrocarbons and heavy metals such as lead and mercury.

2.10 GEOCHEM division of TERRA VAC

(Soil washing - heap leaching)

TECHNOLOGY DESCRIPTION:

Recent efforts at soil washing have encountered difficulties largely associated with liquid / solid separation. GEOCHEM achieves cost-effective soil leaching by a technology transfer from the mining industry's heap leach procedure, which has been used to process large volume / low grade material, such as 0.03 oz. gold/ton ore.

Heap leaching technology involves the placing of contaminated soil, sludge, or solid waste on a drainage blanket over an impervious pad and percolating appropriate leach solutions through the waste, under unsaturated flow. Fine grained waste may require agglomeration. Drainage from the toe of the pad is piped to a recovery / regeneration unit where the metals of concern are recovered and the leach solution regenerated. Leaching, by the close-loop leach cycle, is continued until the solid material is sufficiently leached. If necessary, conventional technologies or other innovative technologies can be used after heap leaching to reduce the geochemical mobility of residual material, to aid in passing the TCLP or similar test. At this time, the remaining solid material no longer is a characteristic hazardous waste. The next batch can be loaded on the heap and leached.

2.11 GEOCYCLE ENVIRONMENT, INC.

TECHNOLOGY DESCRIPTION:

Geocycle Environment has developed a soil washing technology for the treatment of soil contaminated by organic and inorganic compounds. This volume reduction technology recovers soil particles up to 44 microns in diameter from contaminated soil and produces a clean soil which represents 80 to 95 percent of the initial volume. Within the unit, the soil is washed with water in a trommel, a dewatering screw, and vibrating screens. Chemical agents, such as surfactants or a neutralizer, can be added to the water. The treated soil can be used on site as backfill. The fine fraction (<44 microns in diameter) is recovered for further treatment or disposal. The process water is completely recycled in a closed loop circuit and all the vapors are collected and treated. There is no water discharge or air emissions. Unlike bioventing or thermal treatment, this washing technology can treat soil contaminated by inorganic compounds, such as heavy metals. The unit is portable and can be moved for on site treatment which allows cost savings in the transportation of contaminated soil and backfill fees.

TECHNOLOGY HIGHLIGHTS:

- Continuous operation;
- On-site treatment by portable unit;
- Volume reduction of contaminated soil up to 95 percent;
- Clean soil can be used on site as backfill;
- No water discharge;
- No air emissions;
- Can treat soil contaminated by organic and inorganic compounds.

TECHNOLOGY LIMITATIONS:

- Granulometry of soil (less than 25% of particles < 44 microns);
- Complex mixture of contaminants can generate water recycling problems.

OTHER COMMENTS ON TECHNOLOGY:

This soil washing technology was developed by Geocycle Environment with the support of Canada and Quebec Ministries and with the participation of Hydro-Quebec. A two tons per hour unit was built for treatability study and demonstration.

2.12 HARBAUER¹

TECHNOLOGY DESCRIPTION:

The Harbauer process is unique because it uses a low frequency vibration step to improve contaminant removal; it is especially effective in soil with small particles. Harbauer claims the process can effectively clean all particles larger than 15 μm compared with 63 μm , which is typical of conventional soil washing processes. A fixed facility with a capacity of 22 to 44 tph has been operating in Berlin since 1986. Other units which can be either mobile or stationary are being planned.

Contaminated soil is screened and passed through an electromagnet before entering the first blade washer where clean gravel, 10mm to 60 mm in diameter is separated. Depending in the application, HCL, NaOH, or surfactants are added to the slurry which then enters the low-frequency vibration unit. From here the slurry enters a second blade washer where a clean sand fraction (0.2 to 10mm) is separated. A "clean" fine sand (20 μm to 0.2mm) is separated in hydrocyclones and the fines (<20 μm) are separated as a sludge using a belt filter press. The sludge is contaminated and requires further treatment. An extensive water treatment system is included in the system and clean water is recycled to the process.

STATUS:

To date, the Harbauer process has cleaned 11,000 tons of soil contaminated with organics. No data on inorganic removal are available.

2.13 HEIDEMIJ UTIVOERING¹

(Froth Flotation)

TECHNOLOGY DESCRIPTION:

Froth flotation used in the mining industry has been adapted to soil washing by Heidemij Utivoering. The process has been tested on lab- and pilot-scale systems and a full-scale, mobile system was scheduled to begin operation in 1988. This system has a throughput of about 30 tons per hour.

The first step in the process is the removal of coarse particles (>4mm) by wet sieving. The resulting slurry (25% soil, 75% water) is conditioned with "cleaning agents" before entering the flotation cell. The residence time in the cell is dependent on the type of contaminants. The system can have multiple cells for flexibility. The contaminated float (including the soil fines) is skimmed off and either incinerated or sent offsite for disposal. The cleaned soil is dewatered and returned to its original site. Water is completely recycled. No special water treatment is necessary as the VOCs are effectively stripped from the water by air in the flotation process.¹

The process has been used with soils containing a variety of chemicals by slightly adjusting it and using the appropriate proprietary "cleaning agents."

¹ Adapted from Gerber and others, 1991

STATUS:

The Heidemij system has not been used to treat soils with a fines fraction ($<50\ \mu\text{m}$) over 20%; it is not economically practical and the efficiency of the soilwashing process is not good enough to reach accepted standards.

2.14 HEIJMAN MILIEUTECHNIEK BV¹

TECHNOLOGY DESCRIPTION:

Heijmans has developed a simple, semi-transportable soil washer capable of handling 11 tons per hour. Initially the feed stock is wet sieved to separate out larger than 100mm coarse material. Soil particles larger than 5 mm are also separated out and sent to a scrubbing unit. The slurry of smaller than 5 mm particles are mixed in an extractor (which is referred to as a scrubber) with "unidentified extracting agents and oxidizing chemicals." The solids from the scrubber ($>63\ \mu\text{m}$ and $<5\text{mm}$) are passed through hydrocyclones and a dewatering sieve. This cleaned sand is often used as an aggregate for asphalt. The scrubbing water and the contaminated fines ($<63\ \mu\text{m}$) are further treated by coagulation, flocculation and precipitation followed by froth flotation to remove additional solids.

STATUS:

The Heijmans soil washing plant has been in use since 1985 for the removal of cyanides, water-immiscible and low density hydrocarbons, heavy metals (such as Cr, Cd, Ni, Pb and Zn), and combinations of these contaminants. The process has been used on soils with fine fractions ($<63\ \mu\text{m}$) up to 30%, but it works best on sandy soils with a minimum of humus-like compounds.

2.15 HMZ BODEMSANERING BV¹

TECHNOLOGY DESCRIPTION:

This process combines particle sizing, soil washing, and water treatment. The system was designed to be mobile but has become a fixed treatment facility with a capacity of 22 tons per hour. The soil is wet sieved to remove larger than 50 mm coarse material and then larger than 4 mm particles. The rest of the soil is fed to a scrubber with two mixing propellers. Typically, the pH is adjusted to 12 - 13 by addition of NaOH and detergents. After scrubbing, the fines ($<63\ \mu\text{m}$) are removed by hydrocyclones and dewatered. The majority of the contaminants are concentrated in this fraction of the soil, which requires further treatment or disposal. The cleaned sand ($>63\ \mu\text{m}$ and $<4\text{mm}$) may be used as asphalt aggregate or returned to the site as fill. The contaminated scrub water and overflow from the wet sieves, hydrocyclones, and belt press are cleaned in a water treatment system. Process water is treated by precipitation, neutralization, coagulation, and flocculation to remove dissolved contaminants.

STATUS:

The full-scale HMZ system has operated since 1984. HMZ claims it can be used to remove a variety of chemicals including: complex and free cyanides, heavy metals (such as Pb, Zn, Cr, As, and Hg), aromatics and chlorinated aliphatic and chlorinated aromatic hydrocarbons. From an economic standpoint, when the fines fraction of the soil is greater than about 20% of the original volume, the volume reduction of contaminated soil is generally not sufficient to warrant treatment.

2.16 HYDRIPLEX, INC.

TECHNOLOGY DESCRIPTION:

Hydriplex Incorporated has developed a unique soil washing technology that uses its HP-80 compound (a modified sodium silicate) and the hydrocleaner (a soil washing machine) to clean hydrocarbon contaminated soil and hydrocarbon sludge. The HP-80 is soluble in water and not soluble in oil.

A solution of HP-80 and water, mixed at one percent by volume, is used to wash the soil or sludges. The soil or sludge is introduced into the hydrocleaner and goes through a series of augers to completely mix the HP-80 solution and the soil or sludge at a temperature of 140-150 degrees Fahrenheit. As the hydrocarbon contaminated soil/sludge is contacted by the HP-80 solution, the solids are coated with the HP-80 and are dropped from the hydrocarbons. The hydrocarbons separate instantly from the solids and are skimmed from the solution. The solids are moved over a 100 mesh shaker screen (dewatering unit) and collected in a bin. The HP-80 solution is run through a desilting unit to remove the fines and then recirculated back to the augers for continuous cleaning.

What makes this system unique is that it is a closed loop system and the HP-80 is reusable. The only additions of HP-80 and water needed are that percentage of water and solution that are not extracted from the soil (three to five percent), making this a very competitive technology.

The results obtained with the HP-80 and hydrocleaner are 99.99 percent clean, salable oil, and soil with less than 200 ppm that can be put back in place. The unit is completely portable and comes in 20 ton per hour and 5 ton per hour size.

The HP-80 is biodegradable, non-toxic, and non-flammable.

TECHNOLOGY HIGHLIGHTS:

The HP-80 technology treats soils and sludges contaminated with any hydrocarbon, from simple crude oil to benzene, xylene, or toluene.

The advantages of cleaning soil or sludges on site where solids can be used as fill, having a salable oil product and water that can be readily discharged make the HP-80 technology unique to the industry.

There are no air emissions to contend with and the HP-80 technology can clean soil at one half the cost of other alternative processes.

The hydrocleaner is capable of cleaning 500 tons of contaminated soil per twenty-four hours and has no temperature or climate limitations.

TECHNOLOGY LIMITATIONS:

The HP-80 technology is effective in removing heavy metals and acids from hydrocarbon contaminated soil. However, these substances cannibalize the HP-80 compound and higher concentrations of the HP-80 are necessary, that is, three to five percent by volume instead of one percent.

The HP-80 is not suited for radioactive, PCBs or pesticide contamination.

OTHER COMMENTS ON TECHNOLOGY:

The HYDRIPLEX HP-80 technology has been used successfully in bench-, pilot- and full-scale field operations. The hydrocleaner and the HP-80 are in full production and are readily available.

The HP-80 compound is also being used to increase oil and gas well production, to clean produced oil contaminated with iron sulfide bacteria, and is currently being tested in removing hydrogen sulfide from natural gas.

2.17 INTERA

TECHNOLOGY DESCRIPTION:

INTERA's affiliate, FLO TREND Systems, has developed an innovative alternative to disposing of contaminated soils in a landfill. The FTS Continuous Soil Washing System (CSWS) was designed to remediate excavated soil on-site where the recovered soil may be replaced in the excavated area. The CSWS is a chemical/mechanical method to remediate soil by permanently removing oil, heavy metals, and other contaminants. The CSWS will also recover oil and other hydrocarbons for reuse. Single system capacity is 10,000 barrels per day of recovered oil and 2,000 cubic yards soil recovery.

In the CSWS process, particle size distribution is a key physical parameter for determining the number of stages in the total procedure. If oversized material is present, a vibratory screen classifier equipped with spray nozzles is used to segregate and wash the larger particles. The matrix of coarse soils is very amenable to a simple spray washing with a surfactant solution as the material is conveyed down the vibratory screen classifier. The smaller particles that pass through the screen openings with the surfactant solution are conveyed to the primary washing system. Before the washing process is started, the clarifiers are charged with a specially formulated surfactant.

As the sand/soil enters into a first stage clarifier, the solid particles are rapidly mixed, blended, and sheared in the surfactant bath with jet mixers. As the slurry rises in the clarifier, oil will begin to coalesce in oleophilic settling tubes. The oil gravitates over a weir into a trough and is routed to the trough of the second stage clarifier. The remaining slurry in the first classifier is processed by a centrifugal pump to the second stage clarifier for additional mixing, blending, and shearing to further detach the small colloidal and silt particles from the larger particles. As the particles are separated through these shear forces, the surfactant preferentially displaces oil and other contaminants from the individual particles.

The first and second stage washing removes the majority of the oil from the soil. The slurry is further processed through a jet shear / hydrocyclone assembly where centrifugal force in the hydrocyclones continues to scrub the particles. In addition, the hydrocyclones separate the majority of the liquids from the solids. The concentrated solids are discharged from the apex (underflow) of the hydrocyclones, and processed through a three-stage decanting centrifuge.

The cleaned soil discharged from the centrifuge is ready for spreading. The water phase is routed back to the first stage clarifier for reuse and the oil is sent to storage. In the treatment of volatile and nonvolatile metals and other contaminants such as PCBs, an additional treatment may be needed for the surfactant solution before it can be regenerated.

Portable FTS Continuous Soil Washing Systems are available on float trailers or may be mounted on skids. The convenience of a portable unit eliminates the cost and hazards associated with transporting material off-site.

The CSWS has proven to be a cost competitive alternative to other methods of treating contaminated soil, and while the costs of treatment by landfilling and incineration continue to rise, the cost associated with soil washing will likely decrease as the technology becomes more refined.

2.18 KINIT ENTERPRISES

TECHNOLOGY DESCRIPTION:

Kinit Enterprises, Inc., has developed an innovative process for decontaminating soil. The number 1 thermal pit is lined and sized for weight and volume. Extracted oil and humus and other floating debris will be skimmed off by a pipe network similar to that of a pool. Sludge is collected in a number 2 processing pit. A slurry pump will be used to pump soil through a dewatering cycle; this water is returned to the number 1 thermal pit. The soil continues through a rinse procedure to remove any excess salt and wetting agents. This same rinse water is directed to a number 3 processing pit. The rinse water is brought from a number 4 rinse pit. The ozone-processed, flocculated, filtered water runs through a reverse osmosis system to remove salts. The system will also work for other than petroleum contaminated soils, such as hazardous wastes, heavy metals, PCB's, SVOC's, VOC's, and so forth. The decontamination process pumps the slurry through our specially designed injection slip slurry ozone contactor. The slurry is contacted two to three times. Contact time varies with type and concentration of contaminants. The process continues to repeat pits number 1, number 2, number 3 and number 4. Vapor emissions are controlled by our specially designed ozone system.

TECHNOLOGY HIGHLIGHTS:

Trozone Soil Remediation System Technology Highlights

1. The Trozone Soil Remediation System handles all contaminants, PCB's, PAH's, pesticides, VOC's, and heavy metals.
2. The Trozone System is self cleaning and operates a total closed-loop process system.
3. The Trozone System incorporates an enzyme reduction, and it processes as needed.
4. The water purification is accomplished by an ozone bypass system and R.O. system.

TECHNOLOGY LIMITATIONS:

The only technical limitation for the Trozone Soil Remediation System is the inability to eliminate fluorides.

OTHER COMMENTS ON TECHNOLOGY:

There are numerous successful installations of our ozone purification systems that are operating with excellent results.

All systems are custom designed for the specific processing requirements.

2.19 LOCKHEED CORPORATION

TECHNOLOGY DESCRIPTION:

Lockheed offers a variety of remediation systems tailored to the client's need and is continually developing new techniques for characterization and remediation of wastes. The approach used for the decontamination is site specific.

In many cases, the contaminant can be removed through its separation by physical means. The means utilized will be specific to the mineralogic and morphologic occurrence of the contaminant. Some of the physical separations may be aided by the addition of reagents which will increase efficiencies of the operations. The selection of the approach integrates the various

unit operations required to accomplish the decontamination in the most economic manner possible.

Lockheed has successfully designed, constructed, and operated batch and continuous treatment facilities. The mode of operation is typically dictated by the site conditions and the amount of material to be processed.

TECHNOLOGY HIGHLIGHTS:

The decontamination process may utilize the following operations or variations of similar processes:

Screening operations, Gravity separation, Mineral flotation, Magnetic separation (either low or high intensity), or Attribution Scrubbing (wet or dry)

The processes can be very effective in the isolation of a contaminant in a small fraction of the material. The decontamination process may render a portion of the contaminant soluble due simply to its solubility in water or due to desorption of dissolution reactions. This is particularly true in those cases where additives are utilized. The resulting water in any case is likely to require some treatment to allow its recycle.

TECHNOLOGY LIMITATIONS:

The use of all metallurgical techniques can be limited by the nature of the contamination. In cases where the contaminant is disseminated within the entire matrix of the soil, gravity separation and similar physical separation techniques are not applicable for the preliminary isolation of the contaminated fraction. In some cases, the use of hydrometallurgical techniques may prove to be appropriate for the entire contaminated material. If the contaminant is both disseminated and not amenable to economic hydrometallurgical methods, the treatability with volume reduction as the goal may prove to be unachievable. In such an instance, Lockheed immobilization techniques may prove to be appropriate.

OTHER COMMENTS ON TECHNOLOGY:

Full scale processes have been employed successfully to remediate depleted uranium, and uranium process residues. Other systems have been designed for treatment of natural uranium contaminated materials and those processes are in or near the demonstration stage.

Lockheed has also performed work at battery recycling, chloro-alkali manufacturing, electroplating, metal ore mining and smelting, petroleum refinery, inorganic chemical manufacturing, semiconductor manufacturing, rubber manufacturing and landfill sites. Lockheed has performed remediation at RCRA Corrective Action, CERCLA, TSCA, DoD, DOE, and state sites. These projects have ranged from bench-scale, to treatability studies to full-scale cleanups.

2.20 MARCOR MANAGEMENT, INC.

Trade Name: Pneumatic Separation Unit (PSU)

TECHNOLOGY DESCRIPTION:

Marcor, Inc developed a proprietary soil washing technology for in-situ, continuous flow operation to treat heavy metal contaminated soil at an active firing range. The mechanical removal of lead bullet deposits in concert with the application of a chemical fixation reagent removed the source of contamination while simultaneously incorporating the existing lead leachate into a complex molecule, inhibiting future leaching and rendering the soil non-hazardous by current regulatory standards. This two-step process has been proven to economically remove bulk lead and treat residual, lead contaminated soil while allowing beneficial reuse of the treated soil without producing any waste streams.

TECHNOLOGY HIGHLIGHTS:

The advanced chemical stabilization process has been proven to be a cost-effective remediation technique for large-scale lead contamination projects. The remediation method successfully reduces lead leachability while retaining soil-like conditions. The stabilization does not alter starting pH, allowing revegetation.

STATUS:

A proprietary reagent mixing operation has been successfully implemented at a full-scale, 185,000 cubic yard remediation project with total lead concentrations exceeding 70,000ppm and leachable lead greater than 2,200ppm. The reagent was selected for its ability to maintain soil pH and consistency, provide treatment on contact and pass TCLP, SPLP, MEP and Cal Wet testing. The end-use characteristics allow for the beneficial reuse of treated soil on site. The reagent utilizes the lead as a building block to form a pyromorphite mineral, one of the most stable, lead-containing minerals found in nature.

2.21 METCALF & EDDY

Trade Name: HYDRO-SEP

TECHNOLOGY DESCRIPTION:

The HYDRO-SEP soil washing system provides a safe and cost-effective way to manage remediation projects involving large volumes of contaminated soil. Using both screening and hydraulic classification processes, the systems remove the uncontaminated soil components from a contaminated mixture. This reduces the volume of soil requiring ultimate treatment or disposal, increases the amount of material that can be recycled, and eliminates unnecessary treatment or disposal of uncontaminated media. For each soil washing application the HYDRO-SEP system is configured to take account the wide variations in site characteristics and contaminant levels. Only the necessary equipment is included in the configuration thereby reducing project time and cost to achieve optimal volume reduction. The HYDRO-SEP system achieves volume reduction through three primary processes - scalping, primary separation and secondary separation. The scalping process removes gross oversize materials and debris to allow for efficient primary and secondary separation. Primary separation, achieved through physical sizing, uses a variable trommel and vibrating screens, to enhance particle de-agglomeration and provide for field adjustment of separation "cut-points" on a real-time basis. As warranted by site conditions, secondary separation uses multi-fraction gravity separators, jigs, or spiral concentrators to further classify the particles by specific gravity.

WASTE APPLICABILITY:

Clean, oversize material produced by the HYDRO-SEP system has the potential for being returned as backfill to the site. The water used in the process is treated by conventional wastewater treatment technologies and recycled. The concentrated fines can be managed by a variety of techniques, depending on contaminant types and concentrations, including: thermal desorption, biodegradation, chemical extraction, and stabilization / fixation. In conjunction with the HYDRO-SEP technology M&E has developed chemical processes to remove individual metals of interest, including lead. These processes maximize metals recovery for recycling while minimizing sludge for disposal.

STATUS:

M&E used the HYDRO-SEP modular system at the testing range of a Remington Arms munition facility. Preliminary results show a ten-fold reduction in the amount of material requiring leaching as compared to the original anticipated volume; and, performance data indicate that 70 - 80% of the soil was clean after primary processing and suitable for reuse on site. While the system was designed for continuous operation at a rate of 10 tons per hour, the three-month

pilot operation was conducted at a rate of 3 tons per hour and processes over 650 tons of contaminated material.

2.22 MONTANA COLLEGE OF MINERAL SCIENCE & TECHNOLOGY

(Air-sparged hydrocyclone)

TECHNOLOGY DESCRIPTION:

The air-sparged hydrocyclone (ASH) was developed at the University of Utah during the early 1980s to achieve fast flotation of fine particles in a centrifugal field. The ASH consists of two concentric right-vertical tubes with a conventional cyclone header at the top and a froth pedestal at the bottom. The inner tube is a porous tube through which air is sparged. The outer tube serves as an air jacket to evenly distribute air through the porous inner tube. Slurry is fed tangentially through the conventional cyclone header to develop a swirl flow of a certain thickness in the radial direction (the swirl-layer thickness). The swirl is discharged through an annular opening between the porous tube wall and the froth pedestal. Air is sparged through the porous inner tube wall and is sheared into small bubbles. These bubbles are then radially transported, together with attached hydrophobic particles, into a froth phase that forms on the cyclone axis. The froth phase is stabilized and constrained by the froth pedestal at the underflow, moved toward the vortex finder of the cyclone header, and discharged as an overflow product. Water-wetted hydrophilic particles generally remain in the slurry phase and are discharged as an underflow product through the annulus created by the froth pedestal. During the past decade, large mechanical flotation cells, such as aeration-stirred tank reactors, have been designed, installed, and operated for mineral processing. In addition, considerable effort has been made to develop column flotation technology in the United States and elsewhere; a number have been installed in industries. Nevertheless, for both mechanical and column cells, the specific flotation capacity is generally limited to 1 to 2 tons per day (tpd) per cubic foot of cell volume. In contrast, the ASH has a specific flotation capacity of at least 100 tpd per cubic foot of cell volume.

WASTE APPLICABILITY:

Standard flotation techniques used in industrial mineral processing are effective ways of concentrating materials. However, metal value recovery is never complete. The valuable material escaping the milling process is frequently concentrated in the very fine particle fraction. The ASH can remove fine mineral particles that are amenable to the froth flotation process. These particles are generally sulfide minerals, such as galena (lead sulfide), sphalerite (zinc sulfide) and chalcopyrite (copper-iron-sulfide). Finely-divided mining wastes containing these minerals oxidize and release the metallic elements as dissolved sulfates into the groundwater. Particularly applicable are tailings from older operations conducted before the development of froth flotation. Earlier operations recovered minerals by gravity concentration, which did not effectively capture fine particles, and left tailings with relatively large concentrations of fine sulfide minerals.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in June 1990. A pilot plant has operated for the past 4 years. The most recent pilot plant trials on tailings generated by gravity concentration have confirmed both the device's ability to recover sulfide minerals and the high throughput capacity claimed by proponents of the ASH. The pilot plant is still intact and the investigators are in search of waste sites to which the technology might be applied.

2.23 MONTANA COLLEGE OF MINERAL SCIENCE & TECHNOLOGY

(Campbell Centrifugal Jig)

TECHNOLOGY DESCRIPTION:

The Campbell Centrifugal Jig (CCJ) is a mechanical device that uses centrifugal force to separate fine heavy mineral and metal particles from waste materials. The CCJ combines jiggling and centrifuging to separate these particles from a fluid slurry. TransMar, Inc., owns the patents and rights to the CCJ technology. Standard jigs separate solids of different specific gravities by differential settling in a pulsating bed and gravitational field. Jigs operating in this mode can recover solids larger than about 150 mesh (105 microns). Centrifuges are effective in separating solids from liquids but are not effective in separating solids from solids. The CCJ combines the continuous flow and pulsating bed of the standard jig with the high acceleration forces of a centrifuge to segregate and concentrate heavy particles from the waste. The CCJ can recover particles ranging in size from 1 to about 500 microns, depending on whether the particles are sufficiently disaggregated from the host material. The disaggregated particle should have a specific gravity at least 50 percent greater than the waste material. The CCJ does not need chemicals to separate the solids. Appropriately-sized, slurried material is fed into the CCJ through a hollow shaft inlet at the top of the machine. The slurried material discharges from the shaft onto a diffuser plate, which has vanes that distribute the material radially to the jig bed. The jig bed's surface is composed of stainless-steel shot ragging that is slightly coarser than the screen aperture. The jig bed is pulsated by pressurized water admitted through a screen by four rotating pulse blocks. The pulsing water intermittently fluidizes the bed, causing heavier particles to move through the ragging and screen to the concentrate port, while lighter particles continue across the face of the jig bed to the tailings port. The separation's effectiveness depends on how well the original solids are disaggregated from the waste material, and the specific gravity of each solid. The slurried feed material may require grinding to ensure disaggregation of the heavy metals. Operating parameters include pulse pressure, rotation speed or g-load, screen aperture, ragging type and size, weir height, and feed percent solids. The CCJ process produces heavy mineral or metal concentrates which, depending upon the waste material, may be further processed for extraction or sale. A clean tailings stream may be returned to the environment.

WASTE APPLICABILITY:

The CCJ can separate and concentrate a wide variety of materials, ranging from base metals to fine coal ash and fine (1 micron) gold particles. Applications include: 1) remediation of heavy metal-contaminated soils, tailings, or harbor areas containing spilled concentrates; 2) removal of pyritic sulfur and ash from fine coal; and 3) treatment of some sandblasting grit.

STATUS:

The CCJ was accepted into the SITE Emerging Technology Program in May 1992. The CCJ has been evaluated at the Montana College of Mineral Science and Technology Research Center (Montana Tech). Montana Tech has equipped a pilot plant to evaluate the Series 12 CCJ, which has a capacity of 1 to 3 tons per hour. Tests were completed in August 1994 on base-metal mine tailings from various locations in western Montana. A report on these tests is pending. In addition, under the U.S. Department of Energy (DOE) Integrated Demonstration Program, the CCJ was tested on clean Nevada test site soil spiked with bismuth as a surrogate for plutonium oxide. These tests occurred at the University of Nevada, Reno, during August and September 1994. In the future, the CCJ will be tested for its capability to remove radioactive contamination from soils from several DOE sites.

2.24 NEW JERSEY INSTITUTE OF TECHNOLOGY

(GHEA Associates Process)

TECHNOLOGY DESCRIPTION:

The GHEA Associates Process applies surfactants and additives to soil washing and waste-water treatment to make organic and metal contaminants soluble. In soil washing, soil is first excavated, washed, and rinsed to produce clean soil. Wash and rinse liquids are then combined and treated to separate surfactants and contaminants from the water. Next, contaminants are separated from the surfactants by desorption and isolated as a concentrate. Desorption regenerates the surfactants for repeated use in the process. The liquid treatment consists of a sequence of steps involving phase separation, ultrafiltration, and air flotation. The treated water meets all National Pollutant Discharge Elimination System groundwater discharge criteria, allowing it to be: 1) discharged without further treatment, and 2) reused in the process itself or reused as a source of high quality water for other users. In wastewater treatment applications, surfactants added to the wastewater adsorb contaminants. The mixture is then treated in the same manner as described above for: 1) water purification, 2) separation of the contaminants, and 3) recovery of the surfactants. The treatment process yields clean soil, clean water, and a highly concentrated fraction of contaminants. No other residues, effluents, or emissions are produced.

WASTE APPLICABILITY:

This technology can be applied to soil, sludges, sediments, slurries, groundwater, surface water, end-of-pipe industrial effluents, and in situ soil flushing. Contaminants that can be treated include both organics and heavy metals, non-volatile and volatile compounds, and highly toxic refractory compounds.

STATUS:

The technology was accepted into the SITE Emerging Technology Program in June 1990. Treatability tests were conducted on various matrices, including soils with high clay contents, industrial oily sludges, industrial wastewater effluents, and contaminated groundwater. In situ soil flushing tests have shown a 20-fold enhancement of contaminant removal rates. Tests using a 25-gallon pilot-plant have also been conducted. A Bulletin (EPA/540/F-94/509) is available from EPA; a final report will be available in late 1994. Costs for treatment range from \$50 to \$80 per ton.

2.25 ON-SITE TECHNOLOGIES, INC.

Trade Name: CALOCROMA Soil Washing

TECHNOLOGY DESCRIPTION:

The "CALOCROMA" soil washing process utilizes mining and enhanced oil recovery techniques economically and efficiently to achieve immediate separation of hydrocarbons and solvents from the soil. A series of size fractionation and chemical hydration steps are used to accomplish this separation with a minimum of polymerization of the hydrocarbons. The process at pilot-, bench-, and full-scales is continuous and the washing fluid is reused, producing virtually no fluid discharges. The physical-chemical process involves the dissolution of certain contaminants into the extraction liquid and the dispersion of other contaminants into the liquid as undissolved compounds. Complete separation of highly contaminated colloidal suspensions can be consistently achieved. The process is highly effective on contaminated soils ranging from coarse sands and gravels to fine clays. The cleansed soil is separated from the extraction liquid through a series of steps such that residual moisture in the soil is reduced to 3-15 percent, depending on the soil type. The extraction liquid must be disposed of or treated. The processed soil can be immediately reused on the site for backfill or other purposes.

TECHNOLOGY HIGHLIGHTS:

The technology and equipment provide many distinctive features.

1. The equipment is readily available, easily transported to any site, and easy to assemble for operation. The equipment can be prepared for transport and operation on railcars should that configuration of the equipment be needed. The power requirements of the equipment can be satisfied with either portable generators or on-site power.
2. The system has a processing capability ranging from 200 to 1,000 tons per day (24 hours per day operation), and can be operated in any type of weather condition, other than arctic conditions.
3. The technology creates a treatment system that produces minimal air emissions of contaminants and virtually no water discharges. The technology has previously received operating permits and 1,166 excavation permits from the California South Coast Regional Air Quality Management District.
4. The technology achieves very rapid and reliable processing rates, which consistently meet or exceed regulatory requirements. The process is, therefore, more cost-effective than many conventional treatment technologies for cleaning soil and is superior to other available soil washing techniques.
5. The treated soil can be reused on the site, thus eliminating the need for importing backfill material and the costs associated with transportation and disposal of contaminated soil.

TECHNOLOGY LIMITATIONS:

The process is theoretically applicable to nearly any organic compounds, most metals, and certain inorganic compounds associated with soil. However, testing of the process has, to date, been limited to: petroleum hydrocarbons, pesticides, solvents, lead, and copper. There are no limits to concentrations which can be treated, however treatment time and cost vary with concentration. A wide range of soil conditions (pH, soil type, and moisture content) can be effectively treated. There are no serious sitting or permitting problems for the equipment.

OTHER COMMENTS ON TECHNOLOGY:

The technology is ready for immediate application to sites with 5,000 tons or more of contaminated soil. Two sizes of units are available: one for sites with 5,000 - 10,000 tons and one for sites with 10,000 tons and larger.

Pilot testing and demonstration can be provided at client sites or company locations. The technology has been operated on several sites, including a site where 30,000 tons of contaminated soil were treated.

The technology has obtained applicable operating and air quality permits in the Los Angeles basin.

2.26 PITTSBURGH MINERAL & ENVIRONMENTAL TECHNOLOGY, INC

TECHNOLOGY DESCRIPTION:

Pittsburgh Mineral & Environmental Technology, Inc. (PMET) has developed a combination hydrometallurgical / physical separation (HPS) process designed for removing and recovering lead and other heavy metals from wastes including soils, spent blasting abrasives, foundry sands, and other wastes by means of a leaching process that utilizes a basic lixiviant. Typically, this process is applicable to wastes in which lead contamination is in a non metallic state or chemically bound within the overall waste matrix. The process, which renders the treated matrix

material characteristically nonhazardous and generates a recyclable lead concentrate, completely eliminates the need to landfill hazardous waste and breaks the generator's chain of liability regarding disposal of such waste. The process removes the lead from the contaminated matrix material through a combination of 1) dissolving the bond between the lead contaminant and the matrix followed by 2) physically separating the fine lead component from the remainder of the matrix. The only materials exiting the HPS process are the lead-free matrix material, a lead-bearing filter cake sent for recycling, and a non hazardous crystallized salt product generated during adjustment of the pH of the process solution. All fluids are recycled.

STATUS:

Results obtained from pilot-scale treatability studies performed at PMET's facilities have demonstrated that the technology: 1) is capable of reducing the residual lead content in the processes residue to below 100 ppm; 2) renders the processed residue characteristically nonhazardous as determined by TCLP testing; 3) recovers the lead in a form suitable for refining / recycling; 4) produces no liquid effluent, hazardous secondary wastes, or harmful gaseous process emissions; 5) can be designed for batch or continuous operation; and 6) can be configured for either fixed or mobile operation.

Results from tests performed to date on abrasives, foundry sands, and soils indicate that concentrations of lead in the waste matrix can be reduced from several percent to less than 100 ppm and that approximately 80% of the original material is recovered as a non-hazardous, reusable product.

2.27 RISK REDUCTION ENGINEERING LABORATORY and IT CORPORATION

TECHNOLOGY DESCRIPTION:

This technology was developed by EPA's Risk Reduction Engineering Laboratory (RREL) and IT Corporation (IT) for on-site decontamination of metallic and masonry debris at Comprehensive Environmental Response, Compensation and Liability Act sites. The full-scale debris washing system (DWS) consists of dual 4,000-gallon spray-wash chambers that are connected to a detergent solution holding tank and rinse water holding tank. Debris is placed into one of two 1,200-pound baskets, which in turn is placed into one of the spray-wash chambers using a 5-ton crane integral to the DWS. If debris pieces are large enough, the crane places the debris directly into one of the two chambers. Process water is heated to 160 degrees Fahrenheit using a diesel-fired, 2,000,000-British-thermal-unit-per-hour (Btu/hr) water heater and is continuously reconditioned using particulate filters, an oil/water separator, and other devices such as charcoal columns or ion exchange columns. About 8,000 to 10,000 gallons of water is required for the decontamination process. The system is controlled by an operator stationed in a trailer-mounted control room. The entire system is mounted on three 48-foot flatbed semi-trailers and can be readily transported from site to site.

WASTE APPLICABILITY:

The DWS can be applied on site to various types of debris (scrap metal, masonry, or other solid debris such as stones) contaminated with hazardous chemicals such as pesticides, dioxins, polychlorinated biphenyls (PCB), or hazardous metals.

STATUS:

The first pilot-scale tests were performed in September 1988 at the Carter Industrial Superfund site in Detroit, Michigan. PCB reductions averaged 58 percent in batch 1 and 81 percent in batch 2. Design changes based on these tests were made to the DWS before additional field testing. An upgraded pilot-scale DWS was tested at a PCB-contaminated Superfund site in Hopkinsville, Kentucky, in December 1989. PCB levels on the surfaces of metallic transformer casings were reduced to less than or equal to 10 micrograms PCB per 100 square centimeters ($\mu\text{g}/\text{cm}^2$). All 75

contaminated transformer casings on site were decontaminated to EPA cleanup criteria and sold to a scrap metal dealer. The DWS was also field tested in August 1990 at the Shaver's Farm Superfund site in Walker County, Georgia. The contaminants of concern were benzonitrile and Dicamba. After being cut into sections, 55-gallon drums were decontaminated in the DWS. Benzonitrile and Dicamba levels on the drum surfaces were reduced from the average pretreatment concentrations of 4,556 and 23 $\mu\text{g}/100\text{ cm}^2$ to average concentrations of 10 and 1 $\mu\text{g}/100\text{ cm}^2$, respectively. Results have been published in a Technology Evaluation Report (EPA/540/5-91/006a), entitled "Design and Development of a Pilot-Scale Debris Decontamination System." A manual version of the full-scale DWS was used to treat PCB-contaminated scrap metal at the Summit Scrap Yard in Akron, Ohio. During the 4-month site remediation, 3,000 tons of PCB-contaminated scrap metal (motors, cast iron blocks) were cleaned on site. The target level of 7.7 $\mu\text{g}/100\text{ cm}^2$ or less was met, in most cases, after a single treatment with the DWS. The cleaned scrap was purchased by a scrap smelter for \$52/ton. The net costs for the on-site debris decontamination ranged from \$50 to \$75 per ton. The automated, trailer-mounted DWS is scheduled for deployment to a hazardous waste site in The Netherlands for an initial demonstration of the new system. RREL and IT estimate that the system can decontaminate 50 to 120 tons of typical debris per day.

2.28 SCIENTIFIC ECOLOGY GROUP (SEG)

TECHNOLOGY DESCRIPTION:

The SEG soil washing system is an integrated process that uses a combination of physical particle separations and chemical extraction to remove contaminants from the soil. The process is effective at treating soils contaminated with radionuclides, heavy metals, organics, and mixed waste. The general soil washing process consists of several unit operations tied together in an integrated process to separate soil components from contaminating materials, and separate the contaminants from each other. The general process is modified to fit the needs of a particular site by changing the extraction solution chemistry and particle separations. The number of combinations of site soil and contaminant characteristics make the use of a treatability study mandatory, but the flexibility in the general soil washing process allows a wide degree of latitude in its application. The SEG Soil Washing Process minimizes the waste streams by treating and reusing the extraction solution, dewatering the solids, and recovering, or concentrating the contaminants in a significantly reduced volume of soil. The system is capable of treating 20 tons of soil per hour at full-scale. The main soil processing equipment is mounted on three flat bed trailers and support equipment is transported by five additional trailers. The system consists of a 1) soil feed system which consists of a front end loader to deliver feed stock to a Feed Bin where large rocks and other objects are screened out of the soil stream; 2) Washing Trailer where the physical separation is performed and where the extractant solution is applied to remove soluble contaminants; 3) A Separation Trailer that contains the process equipment to treat the effluent from the Washing Trailer and 4) The Filtering Trailer that receives wet processed soil from the previous trailers for dewatering and removal of any remaining leachate.

STATUS:

The SEG Soil Washing system has been successfully implemented at a number of remediation sites. In a recent project in Bruni, Texas, a major soil remediation project was undertaken where 22,500 tons of soil contaminated with uranium and radium were successfully decontaminated to meet the Texas Department of Health limits. The system has also treated soils at a copper contaminated industrial site in Slymar, California, a PCB contaminated site in Dartmouth, Massachusetts, Hexavalent chromium contaminated soil as well as lead contaminated sand contaminated as a result of a sandblasting operation. In all instances, the SEHG Soil Washing System has met or exceeded the cleanup requirements of the regulatory authorities.

2.29 SMITH ENVIRONMENTAL TECHNOLOGIES CORP.

TECHNOLOGY DESCRIPTION:

Smith Environmental Technologies Corporation (Smith) has proposed a preliminary concept for a 2 to 3 ton per hour lead removal soil separation system. The process utilizes conventional shaker screens and other skid mounted, modular processing equipment utilized by Smith Environmental and Swaco (teammate Swaco Geolograph) for soil washing and processing drilling mud and cuttings will be coupled with the Kuryluk Mineral Separator (KMS) to recover and concentrate lead. The KMS is described as a hydraulic mineral separator using water as a treatment medium without the addition of chemicals or heat. The ability to separate heavy metals is achieved due to the contrast in specific gravities between the components. Metals such as lead having higher specific gravities preferentially drop to the bottom of the unit for collection, while lighter materials are forced upwards and eventually out of the unit. The unit has been extensively tested on beach sands at a pilot scale of 20 tons per day, and has been successfully utilized at a Canadian Chlor-Alkali plant to remediate 1000 tons of mercury contaminated soil. Soil Mercury was reduced from 30,000 ppm to less than 10 ppm in a single pass through the system.

The KMS Separator is a self contained, modular unit that can handle 20 tons per day and greater of soil. Both mobile and modular configured units can be made available depending upon the type and volume of soil or other contaminated media to be processed.

Test results from site characterization and laboratory studies on the site soils coupled with the forthcoming bench testing phase of the project will be used by Smith to determine if an additional acid leaching and precipitation step is necessary to process the less than 200 mesh soil fraction. If acetic acid is utilized, the soluble lead acetate formed can be precipitated using a strong acid such as sulfuric to form lead sulfate or with caustic soda to form lead hydroxide. The KMS can be constructed of chemical resistant materials to allow its dual use as both a physical and an acid leaching / precipitate concentrator. The degree to which individual soil and lead concentrate sidestreams are processed will depend upon the overall site cleanup goals and the lead concentrate specification of the receiving lead recycler or smelter. The objective is to process the soil with the least number of steps to minimize handling costs and to produce a lead concentrate that will defray some of the processing costs. Experience has shown that the concentrate must be at least 80% solids and have a lead concentration of 70% to be acceptable by a smelter / recycler.

2.30 SOIL TECHNOLOGY, INC.

TECHNOLOGY DESCRIPTION:

Soil Technology, Inc. has developed a bench-scale soil washer for use in treatability studies. Soil washing is an effective means of volume reduction. Its success is based on the principle that soil contaminants tend to be associated with the fines and organic portions of the soil. Soil washing is used to wash contaminants and fines from the gravel and sand portions, effectively separating the contaminated fines and water from the clean portion of the soil.

The rotating trommel designed by Soil Technology is a bench-scale soil washer that can be used to simulate both continuous feed and batch processes. Soil is fed to an attrition scrubbing tank and from the tank into a hydrocyclone. The hydrocyclone separates the fines from the feed stream. The feed stream is fed to a hopper and from there into the rotating wash chamber of the soil washer. The angle of the chamber can be varied to control residence time during washing.

The material passes over a series of slotted screens that separate the 0.002-, 0.004-, 0.010-, 0.020-, 0.030-, and 0.040-inch size material. The wash water is filtered and recirculated counter-currently through the system. The coarse material (sand and gravel) passes out the end

of the washer and is collected. The separation system allows the testing of the various size portions in order to determine the effectiveness of washing the contaminants from a particular grain size range.

Contaminated wash water is collected and treatment options are evaluated to select an effective wastewater treatment. The water is then treated, using the most effective method available. Washed soil is either returned to site or sent off-site to be used as clean fill. The contaminated fines will be treated using a different technology or will be disposed of.

Soil washing parameters that can be varied in testing include: surfactant type, surfactant concentration, water temperature, pH, and residence time. All of these parameters can be varied, using the bench-scale washer, to develop an effective system for scale-up.

TECHNOLOGY HIGHLIGHTS:

Bench-scale soil washing has been used to test the effectiveness of soil washing on soils contaminated with heavy metals and PCBs. In soils containing a low percentage (<50%) of fines, the technology is a highly effective method of significantly reducing the volume of contaminated material. Soil washing with either plain water or water enhanced with a surfactant separates the fines (clay/silt) from the coarse material (sand/gravel). The washed coarse material can be returned to the site. The contaminated fines and water can then be treated using other appropriate technology or can be disposed of.

Additionally, bench-scale soil washing can provide information on surfactant selection and concentration, residence times, pH, and temperature. This information is used in the field for optimization of the soil washing process.

The soil washing process greatly reduces the overall cost of cleanup. Soil washing is a much less expensive treatment than incineration, bioremediation, or solidification / stabilization processes. Soil washing also creates a more homogeneous fines portion, increasing the effectiveness of the chosen fines treatment process. Despite the fact that the fines are treated twice, first in soil washing and then in final treatment, the savings on coarse material treatment greatly outweigh the disadvantage of handling the fine materials twice.

TECHNOLOGY LIMITATIONS:

Soil washing is not generally thought to be an appropriate technology for soils containing greater than 50% fines. Organic matter can usually be separated during the washing process and treated with an alternative process. Particulate metals need to be separated from the soil prior to treatment as they tend to remain with the coarse portion of the material. All determinations of the appropriateness of soil washing should be made on a soil-specific basis.

OTHER COMMENTS ON TECHNOLOGY:

Soil Technology, Inc.'s bench-scale soil washer has been successfully used to demonstrate the effectiveness of soil washing at an Alaska Scrap Yard Superfund site. Site soil contaminated with PCBs and heavy metals was treated.

A soil washing treatability study was performed to determine the effectiveness of soil washing technology for the cleanup of a two acre scrap yard site in Bremerton, Washington. A bench-scale soil washing test was done, using Soil Technology's bench-scale trommel washer on samples contaminated with TPH, lead, and zinc.

Further testing is planned on soils contaminated with metals and TPH.

2.31 TECHNOLOGY SCIENTIFIC, LTD.

TECHNOLOGY DESCRIPTION:

Technology Scientific, Ltd. (TSL) has developed the innovative Flow Consecutor Technology (FCT) (Patented in Canada.). The technology implements the intensively acting tubular agitator, named Flow Consecutor (FC), to replace any traditional agitator, (e.g. a stirred tank), for processing multi-phase mixtures. Required agitation and residence time for processing in a traditional agitator is scaled up to agitation of slurry, as it flows through the designed flow consecutor (FC).

Fluid agitation influences numerous processes, like adsorption of oily contaminants from soil on the surface of added coal particles, (selective coal agglomeration), adsorption of heavy metals from contaminated water on coal particles (de-ionization), solvent extraction of oil contamination from soil, and so forth.

Agitation by FC is usually combined with separation processes. Flotation is commonly used to separate coal agglomerates, while traditional screening or/and sedimentation can be used to separate solids, in such processes like de-ionization or solvent extraction.

A proposed plant consists of a vibrating screen that separates soil fractions, a single screw washer with a hot water (or steam) jet system for coarse material washing, and mixing tanks for the fine fractions of soil and coal-in-water slurry preparation, with oily water from the coarse soil washing used in slurry preparation. The fine soil fractions, together with oily water, are cleaned of oil in the FC units by oil preparation. The fine soil fractions, together with oily water, are cleaned of oil in the FC units by oil adsorption on coal particles. Then, the cleaned soil separation from oil-covered coal occurs in the flotation unit. Finally, solids are separated from the cleaned water, which is recycled back to the process.

TECHNOLOGY HIGHLIGHTS:

Advantages of the FC device over traditional agitators are: reduction of energy consumption (about 100 times), reduction of required space (about 500 times), increased reliability (no moving parts), increased effectiveness (component processes are individually optimized) and environmental friendliness (enclosed piping system).

The FC can be combined with new intensive flotation apparatus (IFA), if flotation is applied to separate the agglomerates from cleaned soil and water. The IFA is a device that creates swirling horizontal forces. The centrifugal forces created determine the separation of the agglomerates at rates 50 times higher than in original gravitational flotation devices. In comparison to a traditional flotation cell in which the process is driven by gravity, the IFA process is more intensive (about 50 times) because it is driven by the centrifugal force of a strongly swirled slurry. Combination of intensive FC and IFA makes the total unit very compact, which is an important factor when the mobility is considered. Oiled coal (or other carbonaceous material) leaving the unit as a final product of the process, can be considered as an enriched fuel.

TECHNOLOGY LIMITATIONS:

The Flow Consecutor Technology (FCT) reviews variables and situations on a "case by case" basis and the optimal configurations are recommended or alternative technologies suggested. However, the process requires coal or other carbonaceous material to be added to the processes slurry. Also, initial pilot tests have to be carried out in order to determine specific formulation.

OTHER COMMENTS ON TECHNOLOGY:

The FC process has been demonstrated on the bench-scale at the Alberta Research Council and at the University of British Columbia.

The 130 kg/h sand cleaning capacity bench-scale plant was set up and tested. Successful results have been obtained for coal agglomeration, diesel fuel and engine oil contaminated sands cleaning, and clean up of water contaminated with oil and Cu, Pb and Zn ions. For example, the amount of contaminants in sands were reduced from the initial above classification level, 50,000 ppm (5.00%) to less than Class B, 380 ppm in case of diesel fuel and less than class C, 2,600 ppm (0.26%) in case of engine oil (British Columbia standards). Initial concentrations of ions of 525 to 378 ppm were reduced to 1 ppm.

A preliminary design of a 5 to 20 ton per hour (tph) mobile unit has been prepared. The plant is mostly based on the commercially available components and its capital cost requirement is around \$500,000. The operating cost of remediation per one ton of soil is estimated from \$20 at 20 tph, to \$60 at 5 tph plant capacity. Full process optimization, however, would require a small 200 kg/h continuous operation pilot plant testing in the first 6 months of project implementation, followed by the full industrial-scale plant erection in the next 4 months. The pilot plant would also be used in commercial remediation projects to determine the optimum cleaning conditions specific to the contaminated site. This would compensate for variations between the types and amounts of contamination, mineralogical conditions and soil fractional composition. A detailed research proposal and a study cost estimate have been prepared by Technology Scientific, Ltd. (TSL) and are available upon request.

2.32 TORONTO HARBOUR COMMISSION

TECHNOLOGY DESCRIPTION:

The Toronto Harbour Commission's soil recycling process removes inorganic and organic contaminants from soil to produce a reusable fill material. The process involves three technologies operating in series. The first technology is a soil washing process that reduces the volume of treatable material by concentrating contaminants in a fine slurry mixture. The second technology removes heavy metals from the slurry by dissolving the metals with acid and selective chelation. The metal dissolution process recovers all metals in their pure forms. The third technology, chemical hydrolysis accompanied by bioslurry reactors, destroys organic contaminants concentrated in the slurry. The three integrated technologies are capable of cleaning contaminated soil for reuse on industrial sites.

WASTE APPLICABILITY:

This technology is applicable to soil contaminated with inorganics and organics.

STATUS:

Toronto Harbour Commission's soil recycling process was accepted into the SITE Demonstration Program in 1991. The soil recycling process was demonstrated at a site within the Toronto Port Industrial District that had been used for metals finishing and refinery products and petroleum storage. Demonstration sampling took place in April and May 1992. The objective of the SITE demonstration was to evaluate the process' ability to achieve the modified Ontario Ministry of the Environment (MOE) criteria for commercial and industrial sites. Detailed results have been published in a Demonstration Bulletin (EPA/520-MR-92/015), an Applications Analysis Report (EPA/540-AR-93/517), a Technology Evaluation Report (EPA/540/R-93/517), and a Technology Demonstration Summary (EPA/540/SR-93/517). These reports are available from EPA.

DEMONSTRATION RESULTS:

The demonstration results showed that soil washing effectively produced clean coarse soil fractions and concentrated the contaminants in the fine slurry. The heavy metals process effectively treated samples of contaminated soil from the Port Industrial Area, lead-contaminated soil from a lead smelter site, contaminated harbour sediments, municipal sewage sludge, and

municipal sewage incinerator ash. The heavy metals process has been licensed to Metanetix Corporation for worldwide application. It is being applied commercially to selective mine metals from acid mine drainage at the Anaconda copper mine in Butte, Montana. The chemical treatment process and bioslurry reactors achieved a 90 percent reduction in polynuclear aromatic hydrocarbon compounds such as naphthalene, but slightly exceeded the MOE criteria for benzo(a)pyrene.

2.33 TUBOSCOPE VETCO ENVIRONMENTAL SERVICES (TVIES)

TECHNOLOGY DESCRIPTION:

Gravel, sand, silt and clays are washed and classified with heated pressurized water in a series of patented countercurrent extraction augers, screens, cyclones and centrifuges. Chemical treatments needed for reducing hydrocarbon, metal and radioactive material concentrations are used where appropriate. Wash water is recycled unless disposal is preferred.

Hydrocarbons can be reduced from several hundred thousand parts per million (ppm) to less than 100 ppm if required. RCRA classified hydrocarbons can be reduced to even lower concentrations. Examples of hydrocarbon remediation include; petroleum, diesel, kerosene, asphalt, polyaromatic hydrocarbons (PAH), pentachlorophenols (PCP) and mixed sludges. Emissions of volatile hydrocarbons are controlled by capturing the vapors and condensing or oxidizing them.

Metals such as lead, cadmium, arsenic, mercury, copper, zinc and radium have been removed from gravels, sands and clay. Metals are removed by combinations of high pressure water spray, chemical washing, and dissolved air flotation with the appropriate acid, base and oxidation or reduction conditions.

Several types of augers are used. The first is designed for chemical addition and mixing. The second is designed for washing contaminants, fine sand, silt, and clay from the soil. The third is used for rewashing fine sand and silt. Clays are rewashed in the final auger. The augers are inclined so that material is conveyed upward through a series of high pressure sprays placed on the side of the auger along which the soil is preferentially pushed. Water preferentially flows down the other side of the auger, so that a multistage counter current washing occurs.

Cleaned sand, and gravel exiting at the top of the auger are dewatered on shaker screens. Floating debris exiting with the wash water is collected with a coarse shaker screen. Silt is isolated with cyclones and clays are flocculated then dewatered with a centrifuge.

TECHNOLOGY HIGHLIGHTS:

The auger system has been used to remediate a variety of materials. These include hydrocarbons and RCRA classified metals as well as radioactive materials. The equipment is modular and can be customized to the requirements of the job. The advantage it has over competing methods is that the equipment is smaller, uses less water and is less expensive to use than other soil washing equipment because TVIES's equipment is designed around counter current extractions.

The cost of a remediation is very dependent on volume and contaminant. The TVIES systems are more flexible in this regard than some other systems in that they can be combined in 20-30 cubic yard per hour increments. Thus, for a single unit, costs begin to level out above a job volume of 2,000 cubic yards. When larger units are operated in parallel, 50,000 to 150,000 cubic yard jobs can be handled very economically.

Hydrocarbon remediation can cost between \$30 and \$100 per cubic yard. Metal remediation can be more complex and can cost between \$30 and \$150 per cubic yard. One advantage of

remediating metals is that it does not appear to be difficult to extract some metals from clay, whereas it is much harder to remove tarry hydrocarbons from clays. Remediation of nuclear materials can cost up to \$600 per yard, if the soil has been packed in drums. Drum handling alone can sometimes be more expensive than the soil remediation.

TECHNOLOGY LIMITATIONS:

TVIES's countercurrent extraction based soil washing auger system can be used to conduct any reaction, extraction, exchange or cleaning process that can proceed at one atmosphere and soil temperatures less than 160 degrees Fahrenheit. However, the equipment should not be used in a process that requires a pH less than 4 or greater than 11. In addition, while emissions can be captured and condensed or oxidized, the equipment should not be used, without modifications, to process contaminants with a vapor pressure above 20 millimeters of mercury. Finally, larger volumes of fine particles adversely affects the cost of any project since more expensive equipment such as centrifuges must be added to maintain capacity.

However, these limitations are those imposed by the needs of past projects. TVIES experienced chemists and engineers are actively developing or adapting new techniques to our equipment.

OTHER COMMENTS ON TECHNOLOGY:

Tuboscope Vetco International began developing the auger based soil washing system to remediate lead and grease contamination at its own site in Deadhorse, AK. TVI, the worlds largest pipeline inspection company, chose to do the job itself since both landfilling in the lower 48 states and mobilizing existing large soil washing equipment to the site were prohibitively expensive. In that job, 6,000 cubic yards of material were processed and 97 percent were remediated with contamination reduced by approximately a factor of twenty. The remaining fines were characterized as nonhazardous, stabilized and landfilled. The project cost \$1.2 million including building equipment, versus up to \$20 million estimated for other methods.

Since that time, TVIES was incorporated, several hydrocarbon, metal and radioactive material projects were completed and a technology development department was formed to find novel solutions for difficult problems.

The technology development department has demonstrated techniques at bench scale to remediate; 1) lead and cadmium in clay, 2) arsenic, cadmium, copper, chromium, mercury, lead and zinc in sand and silt, 3) silt and hydrocarbon sludges that can contain several hundred thousand parts per million (ppm) contamination adsorbed on particles smaller than 50 microns.

At this time TVIES is recognized as one of the few soil washing companies capable of remediating a superfund site.

2.34 WESTERN ENVIRONMENTAL SCIENCE and TECHNOLOGY

TECHNOLOGY DESCRIPTION:

Western Environmental Science and Technology (WEST) has developed a cost-effective process for the on-site extraction of lead from lead contaminated soil generated at shooting ranges. WEST's soil processing strategies are site specific, and remedial requirements are matched with the proper combination of extraction methods (physical, mechanical, and chemical) chemical stabilization (if necessary), and materials' handling methods. The physical and mechanical extraction methods utilized by WEST provide nearly complete extraction of the elemental lead (both coarse and fine particles) as well as the extraction of a significant percentage of the lead corrosion products. If soil subjected to physical and mechanical extraction of elemental lead still contains elevated concentrations of lead-corrosion products, chemical treatment may be required. The selection of chemical extraction and/or chemical stabilization is dependent upon the

concentration, specification, and distribution of residual lead. If the processed soil will not satisfy the site-specific limit concentration for total lead, then chemical extraction will be required. Chemical stabilization should not be required when chemical extraction is incorporated.

STATUS:

The design of the treatment process is based upon analytical and engineering studies. Bench-scale studies are performed at WEST's Process Evaluation Lab (PEL) to define the specific chemical nature of the lead contamination and to evaluate various extraction methods. WEST operates a mobile (PEL) pilot plant to conduct studies with the contaminated soil. Based upon the PEL results, WEST will mobilize a full-scale plant for on-site remediation actions. WEST has successfully developed and applied this process for the remediation of lead contaminated soil at a shooting range at Folsom, CA. Approximately 10,000 cubic yards of soil were contaminated with lead shot, slugs and their fragments over a period of some 40 years. The contaminated soil was considered hazardous waste under California regulations due to total-lead concentrations ranging from 600 ppm to 30,000ppm. The project was monitored by the California Department of Health Services (DOHS) and completed in 1991. The average concentration of total lead for the processed soil was 174 ppm and all processed soil was discharged on site. More than 30,000 pounds of lead were extracted and recycled. The remedial activities at the Folsom project were reviewed by DOHS and a "no further action" ruling was issued for the site.

2.35 WESTINGHOUSE REMEDIATION SERVICES, INC.

Trade Name: The Westinghouse Soil Washing Process

TECHNOLOGY DESCRIPTION:

Westinghouse offers leading edge technology for on-site soil washing of contaminated soils, sludges, and other materials. Soil washing removes the contaminants from soil such that a large portion of the inlet soil is cleaned and discharged with contamination levels below a specified limit. The extracted contaminants are concentrated in the remaining, smaller portion of the soil for disposal. The Westinghouse Soil Washing Process (WSWP) is one of the few such technologies that can treat soils contaminated with organics, heavy metals, radionuclides, and combinations of contaminants.

The WSWP evolved from a combination of Westinghouse mining and remediation experience. The full-scale units are integrated process trains which use equipment originally developed for the mining industry. The process is arranged to form three functional units:

- * an initial screening and wash of coarse materials;
- * breakup of the remaining solids followed by a thorough wash; a high intensity leaching and separation of the contaminated fines from the clean soil.

Westinghouse maintains two full-scale soil washing units. Both process a continuous feed of soil, the larger unit at 20 tons per hour, and the smaller one from 2 to 4 tons per hour. Both units are trailer mounted and can be easily mobilized.

TECHNOLOGY HIGHLIGHTS:

The Westinghouse soil washing technology offers the following unique benefits:

- * designed specifically to use and recycle aqueous-based leachates
- * broad experience base on full-scale operation
- * proven effective in handling soils that are difficult to wash, such as clays
- * costs are competitive with or lower than other treatment technologies
- * compact design, quick set-up, and high capacity (20 tons per hour)
- * proven and documented high efficiency in removing organic contamination

BDM ENGINEERING SERVICES COMPANY

- * both bench- and pilot-scale facilities and capabilities are well developed
- * aqueous-based, biodegradable leachates are used so that soil washing residuals will not pose future contamination problems

OTHER COMMENTS ON TECHNOLOGY:

Westinghouse has completed a major soil washing project which involved remediation of 16,000 cubic yards of material contaminated with metals at site near Bruni, Texas. In addition, Westinghouse has completed bench-, and full-scale pilot testing for the remediation of a wood treating site.

Westinghouse has also successfully performed numerous bench-, and pilot-scale treatability studies. This practical experience base includes performance with the following contaminants and soil conditions:

- * uranium and radium in a 40 percent clay soil
- * copper in a coarse soil
- * polychlorinated biphenyls (PCB) in a sandy soil
- * silty oil landfarm soils contaminated with grease, PCBs, and uranium
- * river/sewer sediments contaminated with mercury and uranium
- * sandblasting sand contaminated with lead
- * clay contaminated with hexavalent chromium
- * sludges contaminated with chrome, nickel, and copper
- * sandy soil contaminated with lead and petroleum hydrocarbons
- * clay soil contaminated with uranium and nickel
- * ash contaminated with lead, cadmium, and zinc

3.0 SOLIDIFICATION / STABILIZATION

3.1 ADVANCED REMEDIATION MIXING, INC.

(formerly Chemfix Technologies/CeTech Resources)

TECHNOLOGY DESCRIPTION:

In this solidification and stabilization process, pozzolanic materials react with polyvalent metal ions and other waste components to produce a chemically and physically stable solid material. Optional accelerators and precipitators may include soluble silicates, carbonates, phosphates, and borates. The end product may be similar to a clay-like soil, depending upon the characteristics of the raw waste and the properties desired in the end product. Typically, the waste is first blended in a reaction vessel with pozzolanic materials that contain calcium hydroxide. This blend is then dispersed throughout an aqueous phase. The reagents react with one another and with toxic metal ions, forming both anionic and cationic metal complexes. Pozzolanic accelerators and metal precipitating agents can be added before or after the dry binder is initially mixed with the waste. When a water soluble silicate reacts with the waste and the pozzolanic binder system, colloidal silicate gel strengths are increased within the binder-waste matrix helping polyvalent metal cations. A large percentage of the heavy metals become part of the calcium silicate and aluminate colloidal structures formed by the pozzolans and calcium hydroxide. Some of the metals, such as lead, adsorb to the surface of the pozzolanic structures. The entire pozzolanic matrix, when physically cured, decreases toxic metal mobility by reducing the incursion of leaching liquids into and out of the stabilized matrices. With modifications, the system may be applied to wastes containing between 10 to 100 percent solids.

WASTE APPLICABILITY:

This process is suitable for contaminated soils, sludges, ashes, and other solid wastes. The process is particularly applicable to electroplating sludges, electric arc furnace dust, heavy metal contaminated soils, oil field drilling muds and cuttings, municipal sewage sludges, and residuals from other treatment processes. This process effectively treats heavy metals, such as antimony, arsenic, lead, cadmium, hexavalent chromium, mercury, copper, and zinc. In addition, when combined with specialized binders and additives, this process can stabilize low-level nuclear wastes.

STATUS:

The solidification and stabilization process was demonstrated in March 1989 at the Portable Equipment Salvage Company site in Clackamas, Oregon. The Technology Evaluation Report was published in September 1990 (EPA/540/5-89/011a). The Applications Analysis Report was completed in May 1991 (EPA/540/A5-89/011). In addition, several full-scale remediation projects have been completed since 1977, including a high solids CHEMSET reagent protocol designed to treat 30,000 cubic yards of hexavalent chromium-contaminated, high solids waste. The average chromium level after treatment was less than 0.15 milligram per liter and met toxicity characteristic leaching procedure (TCLP) criteria. The final product permeability was less than 1×10^{-4} centimeters per second (cm/sec).

DEMONSTRATION RESULTS:

The demonstration yielded the following results:

The technology effectively reduced copper and lead concentrations in the wastes. The concentrations in the TCLP extracts from the treated wastes were 94 to 99 percent less than those from the untreated wastes. Total lead concentrations in the untreated waste approached 14 percent. The volume of excavated waste material increased between 20 to 50 percent after treatment. During the durability tests, the treated wastes showed little or no weight loss after 12 cycles of wetting and drying or freezing and thawing. The unconfined compressive strength of the wastes varied between 27 and 307 pounds per square inch after 28 days. Hydraulic conductivity

of the treated material ranged between 1 10-6cm/sec and 6.4 10-7 cm/sec. Air monitoring data suggest there was no significant volatilization of polychlorinated biphenyls during the treatment process. Treatment costs were approximately \$73 per ton, including mobilization, labor, reagents, and demobilization, but not disposal.

3.2 ANDCO ENVIRONMENTAL PROCESSES, INC.

(Electrochemical in situ chromate reduction and heavy metal immobilization)

TECHNOLOGY DESCRIPTION:

The electrochemical in situ chromate reduction and heavy metal immobilization process uses electrochemical reactions that generate ions for removal of hexavalent chromium and other metals from groundwater. With regard to hexavalent chromium, as contaminated water is pumped from an aquifer through the treatment cell, electrical current passes from electrode to electrode through the process water. The electrical exchange induces the release of ferrous and hydroxyl ions from opposite sides of each electrode. A small gap size, coupled with the electrode potentials of hexavalent chromium and ferrous ion, cause an almost instantaneous reduction of hexavalent chromium. Depending on the groundwater's pH, various solids may form. These solids include chromium hydroxide, hydrous ferric oxide, and a chromium-substituted hydrous iron complex. For in situ chromate reduction to occur, a slight excess of ferrous iron must be provided. This ferrous iron concentration is determined based on 1) the hexavalent chromium concentration in the groundwater, 2) site-specific hydraulics, and 3) the target rate of site cleanup. Dilution is avoided by introducing ferrous ions in situ and using the aquifer's water to convey them. Following injection, soluble ferrous ions circulate until they contact chromate containing solids or chromate ions. In conventional pump-and-treat schemes, chromate dragout results in long treatment times. Through in situ reduction of chromates that are adsorbed on the soil matrix and contained in precipitates, treatment times should be reduced by more than 50 percent. If implemented properly under favorable pH conditions, chromate can be completely reduced without producing sludge. As chromate reduction occurs, iron and chromium solids are filtered out and stabilized in the soil. When precipitates do not form due to unfavorable pH, the system can easily be operated as part of a pump-and-treat process until chromium removal goals are achieved. Eliminating dragout shortens cleanup time and minimizes sludge handling. Another option is to combine a pump-and-treat scheme with in situ chromate reduction to maximize the cleanup rate, reduce aquifer contaminant loads, and provide water for irrigation or industry. Another benefit of this reduction method is that hydrous iron oxide adsorbs heavy metals. When iron solids are immobilized in the soil, concentrations of other metallic contaminants in the groundwater decrease significantly due to adsorption and coprecipitation.

WASTE APPLICABILITY:

A pilot-scale process unit has been designed to treat groundwater contaminated with hexavalent chromium ranging from 1 to 50 parts per million (ppm) and other heavy metals (2 to 10 ppm), including zinc, copper, nickel, lead, and antimony. A full-scale system can be engineered to handle any flow rate as well as elevated contaminant loads. Each system will be designed to achieve all site-specific remediation objectives.

STATUS:

This technology was accepted into the SITE Demonstration Program in June 1992. Sites are being screened for the demonstration in EPA Regions 2 and 10. Although the process can remediate both confined and unconfined aquifers, water from an unconfined source will be treated during the demonstration.

3.3 BEST SULFUR PRODUCTS

Trade Name: CASCADE® chemical stabilization

TECHNOLOGY DESCRIPTION:

In this process, proprietary reagents are mixed into the soil to chemically fix the soluble metals as insoluble metal silicates or sulfides. Although the total metal content of the soil is not changed, testing of the treated soil with either EP toxicity test or the California WET test will indicate soluble metal concentrations within the regulatory limits. Kiln dust and/or portland cement are frequently used to add to the physical stability if the soil has a high moisture content. The chemical reagent and any physical stabilizing materials can be mixed with the contaminated soil in a land farming type operation or in conventional solids mixing equipment.

This process reduces the concentration of soluble metals in soil within regulatory limits. The concentration of total metals in the soil is not changed. Although organic compounds do not enter into the chemical reactions, they may become physically entrapped and become less mobile after treatment is completed. Before initiating chemical fixation, the ultimate point of disposal should be clearly understood and the appropriate regulatory approvals should be obtained.

STATUS:

The CASCADE process is currently and has been used on a number of remediation sites. For example; Control, decontamination and disposal of Mercury at Brooks AFB, Texas; Removal of organic solvents from wastewater ozonization, Japan; Treatment of steel mill dust, Japan; and for the purification of wastewater from nonferrous metallurgy.

For soluble metals concentrations up to 3000ppm, chemical fixation costs from \$50 - \$100 per cubic yard depending on the volume of soil to be treated.

3.4 CONTRACON NORTHWEST

TECHNOLOGY DESCRIPTION:

In the ContraCon process, contaminated soil is mixed with select chemical agents which function to bind the contaminants to the soil. The resulting matrix inhibits migration of the contaminants by sharply reducing the permeability of the soil to water, and by chemically and physically binding the contaminants within the matrix itself.

The contaminated soil is excavated and prepared in the field for treatment. Debris and organic material are removed and the remaining soil screened with any oversized material being crushed and remixed. ContraCon has treated natural soils with fines contents of 75% and greater using this process, and, by adding small quantities of amending materials prior to processing can treat soils approaching 100% fines. Contaminants have included heavy metals such as lead, chromium, cadmium, copper, zinc and nickel.

ContraCon has developed over 50 proprietary "recipes" of admixtures and binders which have proven effective over a wide range of conditions.

The processing plant is microprocessor controlled and has a capacity of 550 tons per shift. It is highly mobile and needs an area 72 x 78 feet.

WASTE APPLICABILITY:

The treated material can be produced in granular form for use as construction fill or landfill cover, in a form such as pre-mix concrete for road construction, or in the form of solid building units such as concrete blocks. If necessary to comply with local regulations, monitoring wells can

be employed at the disposition site to monitor and demonstrate the long-term efficacy of the treatment.

STATUS:

ContraCon used this technique at the pilot-scale clean-up of the Standard Steel Superfund site in Anchorage, Alaska. The demo was a complete success and ContraCon will be initiating a full-scale remediation in the spring of 1996. ContraCon's performance exceeded the expectation of the regulators, consultants and owners. Lead levels in the soil were reduced by 94 - 98+%.

3.5 GEOCON, INC.

TECHNOLOGY DESCRIPTION:

The in situ solidification and stabilization process technology immobilizes organic and inorganic compounds in wet or dry soils, using reagents (additives) to produce a cement-like mass. The basic components of this technology are: 1) GeoCon, Inc.'s (GEO-CON), deep soil mixing system (DSM), to deliver and mix the chemicals with the soil in situ; and 2) a batch mixing plant to supply International Waste Technologies' (IWT) proprietary additive. The proprietary additives generate a complex, crystalline, connective network of inorganic polymers in a two-phase reaction. In the first phase, contaminants are complexed in a fast-acting reaction. In the second phase, macro-molecules build over a long period of time in a slow-acting reaction. The DSM system involves mechanical mixing and injection. The system consists of one set of cutting blades and two sets of mixing blades attached to a vertical drive auger, which rotates at approximately 15 revolutions per minute. Two conduits in the auger inject the additive slurry and supplemental water. Additives are injected on the downstroke; the slurry is further mixed upon auger withdrawal. The treated soil columns are 36 inches in diameter and are positioned in an overlapping pattern of alternating primary and secondary soil columns.

WASTE APPLICABILITY:

The in situ solidification and stabilization process treats soils, sediments, and sludge-pond bottoms contaminated with organic compounds and metals. The process has been laboratory tested on soils containing polychlorinated biphenyls (PCB), pentachlorophenol, refinery wastes, and chlorinated and nitrated hydrocarbons. The process can treat any waste for which a physical or chemical reagent is applicable.

STATUS:

A SITE demonstration, using one-auger, was conducted at the General Electric Service Shop site in Hialeah, Florida in April 1988. Two 10-by-20-foot areas were treated - one to a depth of 18 feet, and the other to a depth of 14 feet. Ten months after the demonstration, long-term monitoring tests were performed on the treated sectors. The Technology Evaluation Report (EPA/540/5-89/004a) and the Applications Analysis Report (EPA/540/A5-89/004) have been published. A four-auger process remediated the PCB-contaminated Hialeah site during the winter and spring of 1990. GeoCon has used the process to complete over 40 in situ stabilization projects throughout the United States. Several significant projects completed to date include: Construction of a 110,000 square foot, 60-foot deep soil-bentonite DSM wall to contain contaminated groundwater from a former waste pond. All DSM permeabilities were less than 10-7 centimeters per second, a first for DSM construction. Shallow soil mixing and stabilization of 82,000 cubic yards of contaminated soils at a former manufactured gas plant site that was ultimately converted to a city park. The equipment has been scaled up to diameters as large as 12 feet. Typical process costs are \$40 to \$50 per cubic yard plus reagent costs. To date, GeoCon has utilized this process to treat over one million cubic yards of contaminated soils and sludges.

DEMONSTRATION RESULTS:

PCB immobilization appeared likely, but could not be confirmed because of low PCB concentrations in the untreated soil. Leachate tests on treated and untreated soil samples showed mostly undetectable PCB levels. Leachate tests performed 1 year later on treated soil samples showed no increase in PCB concentrations, indicating immobilization. Sufficient data were unavailable to evaluate the system's performance on metals or other organic compounds. Each of the test samples showed high unconfined compressive strength (UCS), low permeability, and low porosity. These physical properties improved when retested one year later, indicating the potential for long-term durability. The soil's bulk density increased 21 percent after treatment. This treatment increased the treated soil volume by 8.5 percent and caused a small ground rise of 1 inch per foot of treated soil. The UCS of treated soil was satisfactory, with values up to 1,500 pounds per square inch. The treated soil's permeability was satisfactory, decreasing to 10-6 and 10-7 centimeters per second (cps) compared to 10-2 cps for untreated soil. The wet and dry weathering test on treated soil was satisfactory. Data provided by Geo-Con indicated some immobilization of volatile and semivolatile organics, which may be due to organophilic clays present in the reagent. Data are insufficient to confirm this immobilization. Performance data are limited outside of the SITE Program. Geo-Con modifies the binding agent for different wastes. Treatability studies should be performed for specific wastes. Process costs were \$194 per ton for the 1-auger machine used in the demonstration, and \$111 per ton for a commercial 4-auger operation. More recent experience with larger scale equipment reduced process costs to about \$140 per cubic yard.

3.6 MONTEVERDE INC., ENVIRONMENTAL SERVICES & TECHNOLOGIES

TECHNOLOGY DESCRIPTION:

Monteverde Inc. uses a technology developed by Versar for the US EPA that encapsulates hazardous wastes. Referred to as the TIDE Ash machine it has been tested on lead contaminated silt and clay rich soil from the C and R Battery Company, Inc., superfund site with curing and compression testing conducted by the Materials Laboratory, New Mexico State University in Las Cruces and with lead analyses performed by Versar Labs, Inc., in Springfield, Virginia.

In the TIDE process, contaminated soil or other hazardous substances are mixed with fly ash, bottom ash, water and proprietary ingredients to form a pozzolanic mixture. The mixture is compressed in the shape of blocks so that the volume of soil is approximately one-third of the initial volume. A four step cycle is required to produce construction-grade fly ash blocks or to encapsulate hazardous waste materials: 1) Blending to increase lubricity and trigger pozzolanic action; 2) Filling - the mixture is deposited into the press box; 3) Compression and 4) Ejection

Soil from the C and R Battery Company site was subjected to the above process with the resulting blocks below TCLP limits for lead.

WASTE APPLICABILITY:

The resulting blocks can be disposed of in a standard landfill, however, given their compressive strength and insolubility the vendor suggests an alternative disposal method such as use as a roadbed or as paving bricks.

3.7 PSI TECHNOLOGIES

(a division of Physical Sciences Inc.)

TECHNOLOGY DESCRIPTION:

PSI Technologies has developed a metals immobilization and decontamination of aggregate solids (MeIDAS) process. The technology involves a modified incineration process in which high

temperatures destroy organic contaminants in soil and concentrate metals into fly ash. The bulk of the soil ends up as bottom ash and is rendered nonleachable. The fly ash is then treated with a sorbent to immobilize the metals, as determined by the toxicity characteristic leaching procedure. The MeIDAS process requires a sorbent fraction of less than 5 percent by soil weight. Standard air pollution control devices clean the effluent gas stream. Hydrogen chloride and sulfur dioxide, which may be formed from the oxidation of chlorinated organics and sulfur compounds in the waste, are cleaned by alkaline scrubbers. Fly ash is captured by a particulate removal device, such as an electrostatic precipitator or baghouse. The only solid residues exiting the process are treated soils, which no longer contain organics and will not leach toxic metals.

WASTE APPLICABILITY:

The MeIDAS process treats organics and heavy metals in soils, sediments and sludges. The process has been effective in treating arsenic, cadmium, chromium, lead, nickel, and zinc. The MeIDAS process is applicable to wastes contaminated with a combination of volatile metals and complex organic mixtures of low volatility. Possible MeIDAS process applications include battery waste sites and urban sites containing lead paint or leaded gasoline, or a site contaminated with organometallics from disposal practices at chemical or pesticide manufacturing facilities.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1991. Initial testing, conducted under an EPA Small Business Innovative Research program, has demonstrated the feasibility of treating wastes containing arsenic, cadmium, lead, and zinc. Bench-scale testing under the SITE Program was completed in July 1992. This study demonstrated that organic, lead, and arsenic wastes could be successfully treated with less sorbent (1 to 10 percent of the soil by weight) than previously anticipated. Pilot-scale testing occurred October 1992 and was completed in May 1993. A demonstration of the MeIDAS Process is in the planning stage.

3.8 RMT, Inc.

(In situ chemical treatment)

TECHNOLOGY DESCRIPTION:

RMT has developed four processes for ex situ and in situ treatment of heavy metals. These proprietary chemistries and methods focus on lead, cadmium, chromium, arsenic, copper, and zinc.

The process involves the use of a buffering agent with phosphate compounds to render lead- and cadmium-bearing waste, soil, and contaminated media nonhazardous over a wide range of disposal conditions. This is accomplished by converting the hazardous metals into forms of the metals which are less hazardous and more stable in the environment. Some metals, such as lead, exhibit amphoteric solubility characteristics; that is, they become very soluble at low and high pHs. Since acid is used to leach metals in the TCLP test, lime or lime-based product such as Portland cement or cement kiln dust (CKD) may be used to neutralize the acid in the leaching test and maintain the pH in a range where lead is relatively insoluble. However, when the lime-treated waste is disposed in a nonacidic environment, such as a monofill or industrial landfill, the treated waste may actually leach higher concentrations of metals in the real environment than the untreated waste would have. Therefore, site owners who believe they have solved a RCRA or CERCLA waste problem may actually have created a far worse problem than existed with the untreated waste.

To avoid the high pH caused by Portland cement or lime, RMT uses buffering agents which do not raise the pH as high as lime does. These buffers are used in combination with an acid or salt containing an anion that chemically bonds with and forms substantially nonleachable forms of

metals. RMT's treatment processes satisfy leaching requirements under both acidic and nonacidic conditions (for example, ASTM water leach test).

TECHNOLOGY HIGHLIGHTS:

The RMT process treats soil, waste, and other media contaminated with heavy metals to render the materials nonhazardous. The hazardous metals are combined with other chemicals to form nonleachable compounds, which are extremely stable in nature. Typical doses of treatment chemicals are in the 5 to 10 percent range, resulting in considerably less bulking as compared to conventional treatment methods. The process is applicable to a wide range of contaminated media, as well as to currently generated waste streams, using both ex situ (above ground) and in situ methods. With ex situ, either batch or continuous methods may be used, depending on the contractor's choice of equipment. In situ applications have been implemented using simple tilling equipment to blend the chemicals with the soil in place. Significant advantages in leaching characteristics have been demonstrated over more traditional methods like lime stabilization and Portland cement solidification. Other advantages may include cost savings for the reagents, material handling, transportation, and disposal.

Many states allow the use of the treated soil on site as backfill, as long as it is capped to prevent erosion and direct contact. The treated material has much the same physical and handling properties as the untreated soil.

TECHNOLOGY LIMITATIONS:

RMT's process can reduce the hazard due to leachable metals, but it does not reduce the concentrations of total metals present. Treated soil and materials must still be landfilled, although they no longer need to be treated as hazardous waste. Very high (greater than 10 percent) zinc concentrations impair the ability of the process to effectively treat cadmium, and may result in high dosages of required treatment chemicals.

STATUS:

RMT's chemical treatment technologies have been repeatedly approved by the USEPA and by regulators in many states. RMT has completed remediation projects at the C and R Battery Site in Richmond, Virginia in 1993 and for a large ferrous metals casting facility. At the C and R Battery Site, 38,000 tons of lead contaminated clay-rich soil was stabilized. The production of the treated soil averaged 1,000 tons per day. The process successfully treated materials with total lead content exceeding 12% to a TCLP characteristic level of less than 5mg/L with a majority of the samples below detection limits for lead. The treated materials were then placed in a Subtitle D Landfill for nonhazardous soil. A similar project was recently completed for the Wisconsin Department of Natural Resources at a former battery cracking facility. The soil exhibited lead levels in excess of 50,000 mg/kg. RMT met the negotiated 500 mg/kg "clean level". The soil was treated in-situ and the treated soil passed TCLP and SPLP leaching procedures. 55,000 tons of soil were treated in less than four months at an average throughput of 1,000 tons per day.

Total project cost savings are typically 10% to 75% in comparison to other technologies.

OTHER COMMENTS ON TECHNOLOGY:

RMT's heavy metal treatment process has been utilized on over 200 bench-scale treatability studies, and has been successfully implemented on 20 full scale projects, including one Superfund site. USEPA and State agency approval has been obtained on each of these projects, many times with permission to leave the treated soil on site.

RMT has been developing chemical treatment solutions for heavy metal problems since the early 1980s, and has patented some of the most effective ones. The current technologies can reduce the leaching of lead, cadmium, zinc, copper, arsenic, and chrome when present in soil, sludge, ash, slag, or some mixture of the above items.

3.9 SOLUCORP

Trade Name: Molecular Bonding System (MBS)

TECHNOLOGY DESCRIPTION:

The Molecular Bonding System (MBS) is a process developed for the stabilization of a variety of media contaminated with heavy metals. The process employs a proprietary mixture of non-hazardous chemicals to convert the heavy metal contaminants from their existing reactive/leachable form (usually oxides) into an insoluble, stable non-hazardous, metal-sulfide compound that will achieve TCLP levels far below regulatory limits. The MBS process maintains the pH levels in the media within a range where the insolubility of the heavy-metal sulfides is assured. The system also provides buffer capacity to ensure that the pH is not significantly altered by the addition of acids or caustic to the media. The process has been designed, and proven successful, for wastes classified as D004 through D011, as well as K-listed wastes. Given the chemical similarities of radioactive wastes, it is likely that MBS can be applied to the permanent stabilization of low level radioactive wastes. Furthermore, its ability to alter the form of hazardous contaminants into a non-hazardous form, can provide a unique and cost effective solution to the treatment of mixed wastes. The MBS treatment process is completely mobile and easily transportable to allow for on-site treatment. Waste material is screened and crushed as required to reduce particle sizes to an average inch diameter. Particle size reduction increases surface area, which maximizes contact with the reagents. The waste media is then mixed with powdered reagents in a closed hopper pug mill (the reagent mixture is established through treatability studies for the site specific conditions). Water is then added to catalyze the reaction and to ensure homogeneous mixing. Curing time is essentially immediate and the resulting increase in volume is between 2% - 3%. The treated media is then conveyed to a stockpile. SOLUCORP fully enclosed pug mill is provided with a vacuum system which pulls the exhaust vapors (and odors) through a regenerable-wet scrubber (backed-up by an activated carbon adsorption system) prior to discharge to the atmosphere. The treated media can then be either returned to the original site or disposed in a Subtitle D landfill (the negligible increase in treated waste volume significantly reduces T&D costs, compared to conventional treatment processes).

STATUS:

The MBS process has undergone extensive bench- and pilot-scale testing prior to its successful full-scale commercialization, where reductions in the TCLP levels of hazardous contaminants achieved in the laboratory, were achieved in the field.

The MBS process is the only treatment system that chemically alters the form of heavy metal contaminants into a non-leachable, non-hazardous, stable compound. The treated product is essentially rendered non-hazardous. Conventional stabilization processes require the addition of large volumes of stabilization agents to the treated material and significantly increasing transportation and disposal costs.

3.10 STC OMEGA, INC.

TECHNOLOGY DESCRIPTION:

STC Omega, Inc. (STC Omega), has developed both chemical organic destruction and chemical fixation/solidification technologies that treat inorganic and organic solid hazardous wastes. STC Omega's chemical organic destruction technology oxidizes or dechlorinates selected organic compounds to reduce total contaminant concentrations by more than 95 percent. Leachable organic contaminant concentrations are also reduced to well below regulatory limits.

STC Omega's inorganic contaminant chemical fixation/solidification technology forms insoluble chemical compounds, reducing leachable inorganic contaminant concentrations in soils and

sludges. STC Omega's inorganic treatment technologies are more efficient and often less costly than generic cementitious processes. STC Omega's technology has been successfully implemented on numerous full-scale hazardous waste remediation projects involving up to 100,000 cubic yards of waste. These sites include Superfund sites and industrial sites across the United States and in Italy.

STC Omega has evaluated various materials handling and mixing systems for use on full-scale remediation projects. Materials handling processes include pretreatment processes for screening and crushing contaminated soils, and placement and conveying systems for handling treated material. Mixing systems include various batching plants, pug mills, and high-shear batch mixing systems to properly meter and mix reagents with contaminated soils. STC Omega provides full on-site technical support to ensure effective application of the treatment technologies, documentation, and quality assurance/quality control procedures during the treatment process.

WASTE APPLICABILITY:

STC Omega's technology can treat a wide variety of hazardous soils, sludges, and wastewaters, including the following: 1) Soils and sludges contaminated with inorganics, including most metals, cyanides, fluorides, arsenates, chromates, and selenium soils; 2) sludges contaminated with organics, including halogenated aromatics, polynuclear aromatic hydrocarbons (PAH), and aliphatic compounds; and 3) wastewaters contaminated with heavy metals and emulsified and dissolved organic compounds, excluding low molecular weight organic contaminants such as alcohols, ketones, and glycols

STATUS:

STC Omega's demonstration project was completed in November 1990 at the Selma Pressure Treating (SPT) Superfund site in Selma, California. STC Omega was subsequently selected for the full-scale remediation of the SPT site, which is contaminated with organics, mainly pentachlorophenol (PCP), and inorganics, mainly arsenic, chromium, and copper. The SPT site was successfully remediated in 1993 using STC Omega's treatment process at a considerable cost savings over competing technologies. The Applications Analysis Report (EPA/540/AR-92/010) and a demonstration videotape are available.

DEMONSTRATION RESULTS:

The demonstration had the following results: The STC Omega process reduced total PCP concentrations up to 97 percent. The STC Omega chemical fixation process stabilized the residual PCP concentrations to very low leachable levels (from 5 to less than 0.3 milligrams per liter). STC Omega's technology immobilized arsenic and copper, while chromium remained well within regulatory limits. The treated wastes had moderately high unconfined compressive strength, averaging 300 pounds per square inch (psi) after 28 days, increasing to more than 700 psi after 18 months. Permeability of the treated waste was low (less than 1.7×10^{-7} centimeters per second). The relative cumulative weight loss after 12 wet/dry and 12 freeze/thaw cycles was negligible (less than 1 percent). The STC Omega technology's treatment costs depend on specific waste characteristics.

3.11 TECHTRAN ENVIRONMENTAL, INC.

(Combined chemical precipitation, physical separation, and binding process for radionuclides and heavy metals)

TECHNOLOGY DESCRIPTION:

This technology removes heavy metals and radionuclides from contaminated waters. The process combines the proprietary RHM-1000 powder, as well as a complex mixture of oxides, silicates, and other reactive binding agents, with a contaminated water stream. Selectively enhanced complexing and sorption processes form flocculants and colloids, which are removed through precipitation and physical filtration. The pH, mixing dynamics, processing rates, and powder constituents are optimized through chemical modeling studies and laboratory tests. The contaminants are concentrated in a stabilized filter and precipitate sludge, which is then dewatered. The dewatered sludge meets toxicity characteristic leaching procedure criteria and may, depending on the contaminant, be classified as nonhazardous. The skid-mounted field pilot unit consists of four main components: 1) pump unit, 2) feed and educator unit, 3) mixing tank, and 4) clarifier tank. The centrifugal pump unit can deliver up to 50 gallons per minute (gpm) to the system. Water from the pump passes through a restrictor nozzle in the feed and educator unit, reducing the air pressure at the outlet of an attached hopper unit. RHM-1000 powder is placed in the upper hopper, which is powered by compressed air. The upper hopper delivers a controlled and very low volume of RHM-1000 to the lower hopper. Reduced air pressure draws it into the water stream. The water passes through a two-stage mixing process and is then sent to the mixing tank. A diaphragm pump, driven by compressed air, draws water from the tank's base and reinjects it through a jet nozzle which also draws surrounding water through holes in its base. The mixed water and RHM-1000 powder pass over a weir into the clarifier tank and through a block of inclined coalescing tubes. Precipitates collect in the tank's base and are drained off. Additional conventional filters can be added to the system outflow as required. The process is designed for continuous operation and can be expanded from 25 to 1,500 gpm. This process removes heavy metals and radionuclides to drinking water standards. It can also treat trace levels of naturally occurring radioactive materials (NORM) and low-level radioactive wastes, as well as more heavily contaminated waters.

WASTE APPLICABILITY:

This technology can be used to 1) remediate water, sludges and soils contaminated with radionuclides and heavy metals, 2) restore groundwater from mining operations, 3) treat NORM in water or scale from petroleum operations, and 4) remediate manmade radionuclides stored in tanks, pits, barrels, or other containers.

STATUS:

The process was accepted into the SITE Demonstration Program in July 1991. The demonstration is scheduled for late 1994 at a uranium mine facility in Texas.

3.12 WASTECH, INC.

TECHNOLOGY DESCRIPTION:

This solidification and stabilization technology applies proprietary bonding agents to soils, sludge, and liquid wastes contaminated with organic and inorganic contaminants. The technology uses a reagent to chemically bond with contaminants in wastes. The waste and reagent mixture is then mixed with pozzolanic, cementitious materials, which combine to form a stabilized matrix. Reagents are selected based on target waste characteristics. Treated material is a nonleaching, high-strength, stabilized end-product. WASTECH, Inc.'s (WASTECH), technology uses standard engineering and construction equipment. As the type and dose of reagents depend on waste characteristics, treatability studies and site investigations must be conducted to determine the

proper treatment formula. Treatment usually begins with waste excavation. Large pieces of debris in the waste must be screened and removed. The waste is then placed into a high shear mixer, along with premeasured quantities of water and SuperSet, WASTECH's proprietary reagent. Next, pozzolanic, cementitious materials are added to the waste-reagent mixture, stabilizing the waste and completing the treatment process. WASTECH's treatment technology does not generate by-products. The process may also be applied in situ.

WASTE APPLICABILITY:

WASTECH's technology can treat a wide variety of waste streams consisting of soils, sludges, and raw organic streams, including lubricating oil, aromatic solvents, evaporator bottoms, chelating agents, and ion exchange resins, with contaminant concentrations ranging from parts per million levels to 40 percent by volume. The technology can also treat wastes generated by the petroleum, chemical, pesticide, and wood-preserving industries, as well as wastes generated by many other chemical manufacturing and industrial processes. WASTECH's technology can also be applied to mixed wastes containing organic, inorganic, and radioactive contaminants.

STATUS:

The technology was accepted into the SITE Demonstration Program in spring 1989. A field demonstration at Robins Air Force Base in Warner Robins, Georgia was completed in August 1991. The WASTECH technology treated high level organic and inorganic wastes at an industrial sludge pit. WASTECH subsequently conducted a bench-scale study under glovebox conditions to develop a detailed mass balance of volatile organic compounds in late 1992. The technology is being commercially applied to treat hazardous wastes contaminated with various organics, inorganics, and mixed wastes. The Innovative Technology Evaluation Report will be available in 1995.

3.13 WEST CENTRAL ENVIRONMENTAL CONSULTANTS/THE KEISEL COMPANY

TECHNOLOGY DESCRIPTION:

The Keisel company and their associates use a proprietary Blending Agent in the "complexing" of heavy metals or inorganic contaminated soils and sludges. The technique is analogous to solidification or stabilization. The term "complexing" is preferred because of the complex matrix which is formed around the heavy metal allowing it to comply with leaching tests.

The Blending Agent is added to the heavy metal-contaminated soils along with an appropriate amount of water, generally 10%. This mix interfaces with the soil. During this interface, the reagent adjusts the pH of the soils by a value of 2-3. This allows the metals to solubilize and change into their hydroxides. Once the metal is in its hydroxide form, the molecular structure of the reagent allows the metal to be captured internally in the silicate and calcium structure. The Blending Agent is significantly different and more effective than other forms of stabilization. In other forms the contaminant is captured on the surface of the compound. This requires more compound to be used to pass TCLP or other leaching tests. In this process, a small amount of the Blending Agent is used, generally 3 - 5% by weight, accomplishing the necessary chemical changes which capture the hydroxide of the metal internally. Once inside the calcium/silica/alumina matrix, the metal is, in effect, fossilized and will pass TCLP or other leaching tests. The Blending Agents are nonhazardous. The process can be operated at rates up to 150 tons per hour.

This chemical treatment process is not a traditional solidification/stabilization process. The treated material does not harden and retain its original mechanical properties. Metals are actually converted into compounds which are less soluble in the environment.

4.0 CHEMICAL TREATMENT TECHNOLOGIES

4.1 CORPEX TECHNOLOGIES, INC.

Trade Name: Corpex Technology

TECHNOLOGY DESCRIPTION:

ESI has developed and acquired patents on certain innovative chelation chemicals with unique capabilities for control and recovery of radioactive and other types of hazardous metal ions from soils, concrete, steel, and other materials. ESI products can be applied in a soil wash process that can be targeted specifically to complex and remove undesirable and toxic ions or radionuclides and permit the soil to be returned clean to its site. The process is either batch or semicontinuous and takes place, typically aboveground. ESI patented formulations can remove such contaminants, usually at neutral pH, without the use of acids or caustics, and are effective over a wide range of temperatures. The chemicals can be oxidized after the cleaning process and no undesirable residues are left -- only water, carbon dioxide, carbon monoxide, and nitrogen.

TECHNOLOGY HIGHLIGHTS:

Certain ESI products can sequester targeted metallic species in a chemical mixture, suppressing the ionic character of the target, thus it permits a higher removal efficiency than can be achieved with other available chelation processes.

ESI chemicals are an order of magnitude more effective than other existing chelants in removal of heavy metals and radioactive metal ions, due to their unique molecular structure and enhanced solubility in water. They are effective over a wide range of temperatures, from freezing to boiling, and variable pH, from 1 - 14.

There are no currently known alternative chemical means to selectively dissolve radioactive contaminants in soils. ESI chemicals, however, have demonstrated the ability to dissolve both deposits of radioactive metals as well as other toxic heavy metals locked in compounds. Solutions used in the decontamination process can be destroyed, resulting in greater than 99.99% destruction of all organics present. The destruction process results in precipitation of contaminants, which can then be removed by filtration and ion exchange, for further processing.

TECHNOLOGY LIMITATIONS:

The effectiveness of ESI chemicals has been proven in a variety of difficult industrial and environmental situations; however, full-scale field application systems will require engineering development. ESI has studied a variety of approaches to scaling up its processes and believes existing field application technology can be modified relatively easily to accommodate them.

OTHER COMMENTS ON TECHNOLOGY:

ESI was organized in 1991 to commercialize this technology developed by a prominent nuclear research scientist, whose work within the U.S. Navy's nuclear propulsion program led him to invent and acquire patents, now owned by ESI, for certain new chemical structures with unique capabilities for control and recovery of radioactive metal ions. There is a considerable body of experimental application results surrounding this chemistry, some of which bears a national security classification. Nevertheless, there is broad evidence of its effectiveness not only in marine nuclear plants but also in land-based stations.

4.2 DAVY INTERNATIONAL - ENVIRONMENTAL DIV.

(In-pulp decontamination of contaminated soil)

TECHNOLOGY DESCRIPTION:

The commercial recovery of gold and uranium from ore is currently undertaken using in-pulp processes. In these processes, the suspension of leached ore particles in the leach solution, called pulp, is directly contacted with a solid adsorbent which extracts the metal from solution. The adsorbent is either an ion exchange resin or active carbon. After contact, the loaded adsorbent is separated from the suspension of leached ore particles and the metal desorbed, normally by a stripping step using a suitable aqueous reagent. The adsorbent is then returned to the extraction stage of the process. Davy is developing this process for treatment of contaminated soil using a proprietary contractor for the extraction step.

In the contaminated soil-process, the soil is crushed and screened and then leached with a suitable lixiviant such as a mineral acid. The resulting aqueous suspension or pulp, having a solid content of up to 55 percent by weight, is then passed to the in-pulp extraction stage of the process. Here, the solid adsorbent is added and is transferred counter-currently to the flow of pulp. Extraction of the contaminants by the adsorbent occurs in the contactor, from which issues the loaded adsorbent and the soil suspension free from contamination. The loaded adsorbent is then stripped free of contaminants in a separate step, typically using a mineral acid, and returned to the extraction step of the process. Ion exchange resins and active carbon are commonly used as adsorbents. The contaminant stream can then be further treated to recover or separate the contaminant prior to disposal.

The above process can be applied to the whole soil or to a fraction which has been separated in a pretreatment step such as soil washing. A common pretreatment is to separate the coarse (sands) fraction from the fine (clays) fraction of the soil. The in-pulp process is beneficially applied to the fine or whole fraction of the soil, as it avoids the problems associated with washing and separating fine particles.

The technology also may be applicable to organic contaminants by using a suitable adsorbent such as activated carbon. However, this application has not yet been investigated.

TECHNOLOGY HIGHLIGHTS:

- a) In-pulp technology is applicable to various inorganic (metal) contaminants by selecting an appropriate adsorbent.
- b) The process removes contaminants from very fine materials such as clays and sediments without the need for solid/liquid separation and an extensive washing step.
- c) Dewatering or drying of the feed material is not required.
- d) Contaminants are recovered in a concentrated form.

TECHNOLOGY LIMITATIONS:

- a) Although similar flowsheets can be designed to treat a wide range of contaminants, each soil or sediment type will require its own flowsheet development to accommodate differences in soil type and contaminant type, concentration, and distribution.
- b) Two or more extraction stages may be required for some combinations of contaminants owing to their different chemical behavior.

OTHER COMMENTS ON TECHNOLOGY:

In-pulp technology used in the process was developed by Davy for metals extraction from ores and concentrates and has been successfully operated on the pilot and commercial-scale since the mid 1980s.

Since 1990, a collaborative development to apply this technology to soil treatment has been carried out with a Danish company KKM under the EC Euroenvirom program. The technology also has been accepted into the EPA SITE Program, but no developmental or demonstration activity has been undertaken yet. The Euroenvirom project was undertaken to develop a process for cleaning soils contaminated with toxic heavy metals, for example, Cu, Cr, As, Hg, Pb, Zn, and so forth.

4.3 DELPHI RESEARCH, INC.

(Oxidation/Reduction)

Trade Name: DETOX (SM)

TECHNOLOGY DESCRIPTION:

DETOX(sm) is a patented, catalyzed wet oxidation waste treatment process. Wet oxidation is the nonthermal oxidation of materials, typically organic materials, with oxygen in a water solution. In practice, wastes and oxygen are fed to a reactor where organic compounds are destroyed and many toxic metals concentrated in the solution for eventual recovery or disposal. Any inert solids in the waste must be filtered from the process solution and rinsed before disposal. DETOX(sm) is not an in situ process. The process can be operated as batch, semicontinuous, or continuous, depending on the waste characteristics. Products of the process are typically carbon dioxide, water, any inert solids contained in the waste, and a concentrated residue of any toxic metals as oxides or salts. Because DETOX(sm) is nonthermal, it does not require fuel (other than the waste organic material) and has minimum gaseous output. For wastes with large inert or water fractions, heat input is required from a separate heater system. The low operational temperature and the nature of the catalyst solution typically does not produce any NO_x, SO_x, dioxins, furans, or volatile metals in the gaseous output. The low emissions from the process make offgas treatment less complex than for thermal processes.

Since DETOX(sm) is catalyzed, it is capable of achieving great destruction efficiencies for many organic materials. Destruction efficiencies greater than 99.9999 percent have been achieved in batch destruction tests. Because the catalyst solution is not consumed in the oxidation reaction and is good at dissolving metals, it can accumulate toxic and/or radioactive metals until it is desirable to recover them or to convert the solution to a solid for stabilization and disposal. Additionally, the process has been demonstrated to effectively reduce chromium(VI) to chromium(III) and to precipitate arsenic as an insoluble ferric arsenate which does not leach in TCLP tests.

TECHNOLOGY HIGHLIGHTS:

DETOX(sm) can destroy all organic compounds except fluoropolymers. It is best applied to bulk organic wastes containing toxic and/or radioactive metals. Destruction efficiencies in batch tests have been greater than 99.9999 percent. The reaction proceeds completely to simple products such as carbon dioxide and water. The DETOX(sm) solution dissolves and concentrates arsenic, barium, beryllium, cadmium, cerium, chromium, lead, mercury, neodymium, nickel, vanadium, and other metals with chemical properties similar to any of these. Many metals can be recovered as salts or oxides by simple adjustments of the DETOX(sm) solution. Since the water content of wastes is removed from the process by evaporation, product water is essentially metal-free. DETOX(sm) can also be used to recover elemental iodine, a high-value product, from iodine containing wastes such as iodorganics or organic-contaminated iodine salts. The low operational temperature and the nature of the catalyst solution typically does not produce any NO_x, SO_x,

dioxins, furans, or volatile metals in the gaseous output. The low emissions from the process make off-gas treatment less complex than for thermal processes and simplifies permitting. DETOX(sm) can be implemented in small portable to large fixed facilities. Treatment cost varies depending on application, amounts of waste, and the value of any recovered materials.

TECHNOLOGY LIMITATIONS:

Since DETOX(sm) is an ex situ treatment, it is generally not best applied to great amounts of soils or waters containing small amounts of contaminants, although there may be situations where this would be desirable. Wastes containing significant fractions of non-toxic inorganic materials which are soluble in the DETOX(sm) solution, in particular calciferous materials such as limestone, may not be suitable. Wastes which contain great amounts of sulfides or cyanides are not typically suitable, as they produce hydrogen sulfide or hydrogen cyanide gases when they contact the acidic DETOX(sm) solution.

OTHER COMMENTS ON TECHNOLOGY:

DETOX(sm) has been developed over the past six years through programs under the New Mexico Research and Development Institute and the U.S. Department of Energy. Delphi Research, Inc. is sole owner of patents or patents pending on the technology in the U.S., Europe, Canada, and Japan. The process has been developed through extensive laboratory testing including hundreds of hours of operation of bench-scale treatment units. Design has been completed for a demonstration unit capable of treating 25 kilograms per hour of hazardous or mixed waste. This demonstration unit is scheduled to be fabricated in 1995, and tested with hazardous and mixed wastes at DOE sites in 1996 and 1997.

4.4 ETUS, INC.

(Oxidation/Reduction)

Trade Name: TR-DETOX

TECHNOLOGY DESCRIPTION:

The TR-DETOX is an in situ and/or ex situ detoxification technology which is protected by U.S. and foreign patents issued and pending. The TR-DETOX technology utilizes the synergetic application of specific inorganic and organic reagents which readily percolate the contaminated soils. Heavy metals are reduced to their lowest valence state and rendered insoluble as stable organometallic complexes. The key chemical in the TR-DETOX technology is asodium polythiocarbonate which has remarkable reducing and precipitating capabilities. The resultant precipitate is essentially insoluble and tends to increase its insolubility with time. The detoxified soils easily achieve the Toxicity Characteristics Leaching Procedure (TCLP) requirements and are no longer leachable. The TR-DETOX technology can also be applied in conjunction with simultaneous biological treatment for the in situ and ex situ destruction of organic contaminants. Minimal volume addition to soil at approx. 25 percent of traditional costs.

TECHNOLOGY HIGHLIGHTS:

The TR-DETOX technology does not normally require the use of lime, silicates or portland cement. The reagent may be simply percolated into the soil. Unlike some methods, the TR-DETOX technology actually converts the heavy metals into a permanently stable, non-toxic form. Treatment costs are typically one-quarter or less the cost of traditional methods (portland-cement silicates). Detoxification may be electronically controlled with minimum operator time. Effective for ash and sludge detoxification, soils and river sediments. A very minimal increase in original volume will be experienced with TR-DETOX. Works under all known conditions. Detailed studies are published in the Environmental SOLUTIONS Database.

TECHNOLOGY LIMITATIONS:

To date, the TR-DETOX technology has been adaptable to most remediation applications containing heavy metals. The reagent mix is altered to the site conditions. The only limitation is the need for initial pilot tests in order to determine the specific formulation.

OTHER COMMENTS ON TECHNOLOGY:

ETUS, Inc. has developed numerous chemical and equipment technologies for detoxification, zero-discharge and water reuse assignments throughout the world. The company maintains operations in Japan, South Korea, Europe and Saudi Arabia in addition to its North American Operations. ETUS, Inc. serves directly or indirectly more than 400 of the Fortune 500 companies. ETUS, Inc. participates in the Environmental SOLUTIONS Software Database which is a waste management tool for generators and environmental professionals.

4.5 INTEGRATED CHEMISTRIES, INC.

Trade Name: METRAXT

TECHNOLOGY DESCRIPTION:

METRAXT is an aqueous-based product developed specifically for the cleanup of metals on solid surfaces. METRAXT has the capability of being applied as a foam blanket which allows application to overhead, vertical and horizontal surfaces. METRAXT is formulated to extract metals from porous surfaces by bonding with them.

METRAXT has successfully cleaned surfaces, such as concrete, and asphalt contaminated with metals. In laboratory tests and customer use, METRAXT has demonstrated excellent extraction efficiencies. This efficiency translates into less work, less time and less product usage than conventional cleanup methods.

Application of METRAXT is similar to shampooing a carpet. The METRAXT solution is applied using a foaming device, allowed to penetrate the surface and vacuumed up.

Easy to remove: METRAXT easily vacuums up from surfaces. Surfaces then are lightly rinsed with water, which also is vacuumed off. Easier removal results in lower labor costs.

TECHNOLOGY HIGHLIGHTS:

METRAXT is an aqueous-based system developed for the cleanup of metal contamination from solid surfaces. METRAXT is most effective when applied with a foam generating device. Application of product that is not foamed should be by dilution and application using the same sequence as foamed solutions.

METRAXT has successfully removed chromium and lead that were present at a chemical facility. The analytical results on the pre-rinse compared to the post-rinse indicated a 70% reduction in the presence of chromium.

Approximately 0.08 gallons of waste per square feet were generated. You can adjust the pH of the generated waste and drop the metal out of solution to minimize the waste disposal.

One gallon of METRAXT will clean 100 square feet.

TECHNOLOGY LIMITATIONS:

The application coverage of METRAXT will vary with surface porosity and operator proficiency. The coverage for porous surfaces is 100 square feet per gallon and for non-porous is 125 square feet per gallon. This material is corrosive to metal surfaces and painted surfaces.

High concentration spills: If the concentration of metal is very high, the spill is old, or the site has a history of spills, multiple applications of METRAXT will be necessary to get acceptable results. It is not uncommon when analyzing before and after the first few treatments to get higher readings due to the product's ability to extract metals from solid surfaces.

Cleanup: Because of the chemical activity of METRAXT, the equipment used for application and vacuuming requires routine inspection and maintenance. Hoses and gaskets will have to be periodically replaced. Washing the foamer, its hoses and gaskets with soap and water and rinsing with water is recommended after each use to extend lifetime.

OTHER COMMENTS ON TECHNOLOGY:

METRAXT Case Study Performed at a chemical facility in Houston, Texas.

Precleaning: The concrete sump and the floor drains were pressure washed with clean water and pumped dry prior to METRAXT application.

Mixture: Concrete sump - A one part METRAXT to two parts water mixture was used on the sump because it produced a stiffer foam that adhered to the vertical walls.

Floor drains - A one part METRAXT to three parts water mixture was used here because 80% of the surface to be cleaned was horizontal and the dwell time was achieved with a thinner foam.

Application procedures: The concrete sump was 5 feet in diameter and 5 feet 6 inches deep. Foam was applied to the entire vertical surface and bottom of the sump at one time and allowed to dwell for 5 minutes. The foam was then scrubbed into the surface areas and vacuumed clean. The walls and floor were lightly rinsed with clean water and wet vacuumed. These same steps were repeated two more times except the scrubbing was eliminated.

The concrete floor drains were bermed off using absorbent booms in approximately 30 foot long sections. The drains were 8 inches deep, 12 inches wide, and 250 feet in length. The same steps were used for this application as for the sump.

Analytical procedures: The analytical results on the pre-rinse compared to the post-rinse indicated a 70% reduction in the presence of chromium.

4.6 SEVENSON ENVIRONMENTAL SERVICES, INC.

Trade Name: MAECTITE Chemical Treatment Process

TECHNOLOGY DESCRIPTION:

The patented MAECTITE chemical treatment process for lead and other heavy metals utilizes reagents and processing equipment to render soils, waste and other materials nonhazardous for the characteristic definition of toxicity under Resource Conservation and Recovery Act. The MAECTITE process reduces leachable lead to below treatment standards for listed waste treatment limits required for land-ban regulations (September 19, 1994 40 CFR Parts 268, Final Rule). Lead in treated material complies with leach limits established by EPA as determined by approved methods in SW-846, including, but not limited to toxicity characteristic leaching procedure (TCLP), EP Toxicity test, and the Multiple Extraction Procedure. Chemical treatment by the MAECTITE process converts leachable lead into insoluble minerals and mixed mineral forms within the material or waste matrix. MAECTITE reagents stimulate the nucleation of crystals by chemical bonding to yield mineral compounds in molecular forms. These are resistant to leaching and physical degradation from environmental forces. Durability of traditional monolithic solidification/ stabilization process end-products is often measured by geotechnical tests such as wet/dry, freeze/thaw, permeability, and unconfined compressive strength. Since the

MAECTITE process does not use physical binders, is not pozzolanic or siliceous, and does not rely on the formation of metallic hydroxides using hydration mechanisms, these tests are not relevant to MAECTITE product chemical stability. MAECTITE does not utilize adsorption, absorption, entrapment, lattice containment, encapsulation, or other physical binding principles for treatment success. Effective treatment is not pH dependent and is a true chemical reaction process where the treated material is altered in structure and properties yielding stable compounds. The MAECTITE process uses water as a mixing lubricant. However, the dehydration characteristic of the process liberates water present in waste prior to treatment (absorbed and hydrated forms) to a free state where it can be removed from the waste matrix by evaporation and capillary drying principles. The ability of treated material to readily lose water, the formation of dense mineral crystals, and the restructuring of the material as a result of MAECTITE treatment (where interstitial space is minimized), all contribute to reduced waste volume and weight. Ex situ MAECTITE processing equipment generally utilizes material screening and sizing components, liquid and solid reagent storage delivery subsystems, and a mixing unit such as a pugmill. Equipment is mobile, but can be modified for fixed system operations. In situ MAECTITE processing equipment is also available with system selection largely dictated by contaminant plume configuration, soil characteristics, and site space limitations.

WASTE APPLICABILITY:

By selecting proper MAECTITE treatment chemicals from families of reagents, varying their dosage, and applying appropriate material handling procedures, all material matrices historically subjected to the MAECTITE process have been successfully treated. Materials including soils, sludges, sediments, battery contents including casings, foundry sands, filtercake, furnace slag and matte, debris and construction rubble, carbon dross, wire fluff and chop, shooting range sand with spent projectiles, blasting sand with lead-based paint chips, auto fluff, bird and buck shot, electronic components, glass, fire brick, coatings, and oxide pigments have been rendered nonhazardous. Oversize material can be treated with the process as debris (best demonstrated achievable technology for lead, i.e., chemical treatment), but size reduction often makes processing more efficient. To date, no material has been found resistant to treatment by the MAECTITE process. Even sludges with free liquids (as determined by the paint filter test) have been treated to TCLP compliance when excess fluids are present. The range of lead levels effectively treated has not been fully determined; however, soil with total lead as high as 30 percent (weight) with TCLP values over 4,000 milligrams per liter (mg/l) was not problematic. Common lead levels encountered have averaged from 200 milligrams per kilogram (mg/kg) to 6500 mg/kg with TCLP averaging 20 to 400 mg/l. The final MAECTITE treatment designs are most often determined by the material geochemistry. Furthermore, the correlation between total lead and regulated leachable lead levels have been inconsistent. Treatment efforts have been more strongly related to the waste/material geochemical characteristics.

STATUS:

The patented MAECTITE chemical treatment technology was initially accepted into the SITE Demonstration Program in March 1992. Severson Environmental Services, Inc. acquired the MAECTITE technology in 1993. Combining ex situ and in situ quantities treated, over 250,000 tons of material have been successfully processed. Treatability studies have been conducted on over 50 different materials (including all types of soils) in over 20 states, Canada, Italy, and Mexico. MAECTITE has been applied at full-scale demonstration and remedial projects in 14 states. MAECTITE chemical treatment is a cost-effective technology when compared to traditional offsite options or to other onsite treatment alternatives. With its MAECTITE process, Severson has been formally accepted in the EPA's PQOPS program for the fixation/ stabilization of inorganic species.

4.7 SOLUCORP INDUSTRIES LTD

Trade Name: Mercon (TM)

TECHNOLOGY DESCRIPTION:

Mercon (TM) is a patented liquid mercury vapor suppressant designed to stop and absorb mercury vapors. The chemical process utilized creates a mercuric salt or sulfide. The reagents react with the metal and absorb any ambient vapor. Mercon (TM) products have the ability to stop and absorb any methylation in water. Mercon (TM) products are currently used in commercial and industrial maintenance and remediation. The dilution factor of Mercon (TM) can be adjusted to fit different mercury problems.

TECHNOLOGY HIGHLIGHTS:

Mercon (TM) products are American Dental Association (ADA) approved and have been used in the dental, surgical, and medical laboratory environments for over a decade. Mercon (TM) can be used around humans, and has no noxious smell or harmful characteristics. There are no harmful or caustic effects on machinery, and Mercon (TM) has the property of lubrication as well.

Mercon (TM) offers quick reaction and/or long term reaction, absorbency of existing harmful vapors and the ability to work in water. Mercon (TM) has the ability to follow elemental mercury through a concrete slab and render it nontoxic.

TECHNOLOGY LIMITATIONS:

The Mercon (TM) product is not effective in soils. EPS Environmental has developed another technology called "Quicksilver" that specializes in remediation of soils, sludges, etc.

OTHER COMMENTS ON TECHNOLOGY:

EPS Environmental, Inc. is currently working with many different industrial and medical companies to help solve their mercury contamination problems. EPS Environmental is bench testing and assimilating information and proposals to do a full-scale soil remediation of a heavily contaminated mercury site in northern New Jersey. Additional studies are being conducted on the eventual remediation of various estuaries with high mercury content. Several studies are being conducted for private clients with regard to contaminated sludges and bottom and fly ash, as well as various industrial maintenance programs. EPA has been able to handle all formulations of mercury contamination thus far.

4.8 VIKING INDUSTRIES

Trade Name: Recycle of Metal and Cyanide Ions

TECHNOLOGY DESCRIPTION:

Our premise is based on currently used processing methods and new technology. A metal contaminated site is excavated the same way precious metals are mined. The dirt is piled on a liner or pad. Cyanide is sprayed on the dirt and collected when it reaches the liner. The metal-cyanide solution is stripped of the cyanide and the metals are filtered.

Recycle of metal and cyanide ions by means of Acidification-Volatilization and Recovery (AVR) is a viable method to reduce the cost of cleanup. The above ground process begins when the solution or slurry is pumped into the stripping column. Acid is then metered into the column forming HCN. HCN gas is swept into the adsorption column of caustics thereby making sodium cyanide available for reuse. The system is a closed loop with double wall construction for potential gas entrapment. Monitors and alarms are placed at critical points.

Cyanide solution of complexed metal is "uncomplexed" or broken making processing of the metals much simpler and cost-effective. Process can be batch or continuous. Companies who make cyanide use a continuous process. Residual cyanide in soil is oxidized.

TECHNOLOGY HIGHLIGHTS:

AVR Technology is superior to oxidizing or hypochloriting metal-cyanide solutions from a technical, environmental, and economic point of view.

Separation of metal cations leads to the more efficient removals in uncomplexed form. Dependent on the effluent, efficiencies of 97.3 to 100 percent were achieved.

Cyanide complexed metals treated:

| | |
|--|-----------------------------------|
| nickel chloride | NiCl ₂ |
| cadmium sulfate | CdSO ₄ |
| copper sulfate | CuSO ₄ |
| ferrous nitrite | Fe(NO ₃) ₃ |
| zinc sulfate | ZnSO ₄ |
| mixture of all F007, F008, F009, F010, F011, F012 wastes | |

TECHNOLOGY LIMITATIONS:

The waste must be pumpable. The process is based on liquid flowing down a packed column against a counter-current flow of air sweeping gas to an adsorption column. The process is applicable only for sludge containing cyanide.

OTHER COMMENTS ON TECHNOLOGY:

AVR technology has been used for many years in other countries. Currently several gold mining operations are using this technology in New Zealand and Canada. Most laboratory analyses of cyanide concentrations use technology similar to this process.

5.0 SOLVENT EXTRACTION

5.1 TERRA-KLEEN RESPONSE GROUP, INC.

(Solvent extraction treatment system)

TECHNOLOGY DESCRIPTION:

The solvent extraction treatment system was developed by Terra-Kleen Response Group, Inc. (Terra-Kleen), to remove semivolatile and non-volatile organic contaminants from soil. This batch process system uses a proprietary solvent blend to separate hazardous constituents from soils, sediments, sludge, and debris. The U.S. EPA Office of Pesticides and Toxic Substances has made a written finding that the Terra-Kleen solvent is nontoxic. Treatment begins after excavated soil is loaded into the extraction tanks. Clean solvent from the solvent storage tank is pumped into the extraction tanks. The soil and solvent mixture is held in the extraction tank for a time period sufficient to solubilize organic contaminants into the solvent, separating them from the soil. The contaminant-laden solvent is then removed from the extraction tanks and pumped into the sedimentation tanks. Suspended solids settle or are flocculated in the sedimentation tank, and are then removed. Following solvent extraction of the organic contaminants, any residual solvent in the soil is removed using soil vapor extraction and biological treatment. Soil vapor extraction removes the majority of the residual solvent, while biological treatment reduces residual solvent to trace levels. The treated soils are then removed from the extraction tanks. The solvent regeneration process begins by pumping contaminant-laden solvent from the sedimentation tank through a microfiltration unit and a proprietary solvent purification station. The microfiltration unit first removes any fines remaining in the solvent. The solvent purification station separates organic contaminants from the solvent and concentrates them, reducing the amount of hazardous waste for off-site disposal. The regenerated solvent is pumped into the clean solvent storage tank for use in treating additional soil.

WASTE APPLICABILITY:

The Terra-Kleen solvent extraction treatment system is a waste minimization process designed to remove the following organic contaminants from soils: polychlorinated biphenyls (PCB), chlorinated pesticides, polycyclic aromatic hydrocarbons (PAH), pentachlorophenol, creosote, polychlorinated dibenzo-p-dioxins (PCDD), and polychlorinated dibenzofurans (PCDF). The technology also has the capacity to remove organic contaminants, such as PCBs, from low-level radioactive wastes. The Terra-Kleen solvent extraction system does not require soil screening equipment to remove debris or large objects from the contaminated soil before treatment. The system is transportable and can be configured to treat small quantities of soil (1 to 1,000 cubic yards) as well as large volumes generated at remedial sites.

STATUS:

Terra-Kleen demonstrated its solvent extraction treatment system under the SITE Demonstration Program between May 16 and June 11, 1994. The technology was demonstrated at the Naval Air Station North Island Site 4, in San Diego, California. Soils at Site 4 are contaminated with heavy metals, volatile organic compounds (VOC), semivolatile organic compounds (SVOC) (including PAHs), PCBs (Aroclor 1260), dioxins, and furans.

DEMONSTRATION RESULTS:

Preliminary findings from the Terra-Kleen SITE demonstration are summarized as follows: PCB Aroclor 1260 concentrations were reduced from a maximum of 170 milligrams per kilogram (mg/kg) in untreated soil to approximately 2 mg/kg in treated soil. The average removal efficiency was 98.39 percent. The system can efficiently concentrate PCBs into a smaller waste volume for off-site disposal. The treatment system's PCB removal efficiency was reproducible for all batches run during this demonstration. To provide additional information on the technology's capabilities, samples were also collected and analyzed for VOCs, SVOCs, PCDD,

and PCDF. The analytical data from these samples are not yet available. All findings of the Terra-Kleen SITE demonstration, including sample analytical results, will be discussed in the SITE technology capsule and the innovative technology evaluation report. Additional data is being collected at the Naval Communication Station in Stockton, California. The system is treating soil contaminated with chlorinated pesticides at concentrations up to 600 mg/kg. Preliminary data indicates that target levels of 1 mg/kg are being achieved.

5.2 UNIVERSITY OF HOUSTON

(Concentrated-chloride extraction and recovery of lead)

TECHNOLOGY DESCRIPTION:

This technology is designed to recover lead from soils using an aqueous solvent extraction process. The extraction process takes advantage of the high solubility of chloro-complexes of lead. First, soil is sieved to remove particles greater than 4 millimeters in diameter. The soil is then placed in the chloride extraction tank and extracted with concentrated (greater than 4 molar) chloride solution with a residence time of less than 1 hour (perhaps less than 15 minutes). This slurry then enters a thickener. The bottoms of the thickener are sent by a sand pump to the second chloride extraction tank, where they contact fresh solvent. After contacting fresh solvent for less than one hour, the solution exiting the second chloride extraction tank is sent to the second thickener. The bottoms of the second thickener are sent to the soil rinse system to remove excess salt before the clean soil is placed back on site. The overflows from the second thickener are sent to the first chloride extraction tank, and the over-flows from the first thickener are sent to the lead precipitation system. After lead hydroxide is removed, the spent chloride solution is sent to the solvent makeup unit, where it is prepared for reuse. This system will operate in a continuous fashion and is expected to treat up to 10 kilo-grams per hour (kg/hr) of soil at pilot-scale. Concentrated chloride extraction has been used on actual lead battery waste site (LBWS) soil at laboratory scale. Lead removals of greater than 97 percent were achieved on LBWS soil contaminated with up to 20 percent lead using only a single-step sodium chloride (NaCl) batch extraction. Following these NaCl extraction tests, the treated soils consistently passed the toxicity characteristic leaching procedure test. This project's main objective is to scale up the extraction process to a mobile, pilot-scale unit after optimizing the process at laboratory scale. Four preliminary project goals are to 1) optimize the technology at laboratory scale by determining the effects of varying several process parameters, 2) determine the extraction process mechanism, 3) examine the ability of the process to decontaminate lead-contaminated soils of different soil types, and 4) determine the ability to recycle and reuse the lead-saturated chloride solution. The pilot-scale unit will be designed, constructed, and demonstrated after the project goals have been achieved.

WASTE APPLICABILITY:

This technology removes lead from soil, particularly at battery waste sites. However, this project will also study the feasibility of removing lead from other wastes and removing metals such as cadmium, mercury, silver, copper, and zinc from contaminated soil.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1994. The University of Houston will conduct bench-scale experiments to determine the optimum operating parameters for a pilot-scale unit. Once optimum operating conditions are determined, a mobile pilot-scale unit will be constructed to treat up to 10 kg/hr of soil. Two LBWS in the Houston are being considered for the pilot-scale tests.

6.0 ELECTRO-TECHNOLOGIES

6.1 BATTELLE MEMORIAL

(In situ electroacoustic soil decontamination)

TECHNOLOGY DESCRIPTION:

The patented in situ electroacoustic soil decontamination (ESD) technology treats soils containing hazardous organics by applying direct current electrical and acoustic fields. Direct current facilitates liquid transport through soils. The technology consists of electrodes, an anode and a cathode, and an acoustic source. The double-layer boundary theory is important when an electric potential is applied to soils. For soil particles, the double layer consists of a fixed layer of negative ions that are firmly held to the solid phase, and a diffuse layer of cations and anions that are more loosely held. Applying an electric potential to the double layer displaces the loosely held ions to their respective electrodes. The cations take water with them as they move toward the cathode. Besides ESD water transport through wet soils, the direct current produces other effects, such as ion transfer, pH gradients development, electrolysis, oxidation and reduction, and heat generation. Heavy metals present in contaminated soils can be leached or precipitated out of solution by electrolysis, oxidation and reduction reactions, or ionic migration. The soil contaminants may be 1) cations, such as cadmium, chromium, and lead; or 2) anions, such as cyanide, chromate, and dichromate. The existence of these ions in their respective oxidation states depends on soil pH and concentration gradients. Direct current is expected to increase the leaching rate and precipitate the heavy metals out of solution by establishing appropriate pH and osmotic gradients. When properly applied in conjunction with an electric field and water flow, an acoustic field can enhance waste dewatering or leaching. This phenomenon is not fully understood. Another possible application involves unclogging recovery wells. Since contaminated particles are driven to the recovery well, the pores and interstitial spaces in the soil can close. This technology could be used to clear these clogged spaces.

WASTE APPLICABILITY:

The technology's potential for improving nonaqueous phase liquid contaminant recovery and in situ removal of heavy metals needs to be tested on a pilot scale using clay soils.

STATUS:

Phase I results indicate that ESD is technically feasible to remove inorganic species such as zinc and cadmium from clay soils, and only marginally effective for hydrocarbon removal. A modified ESD process for more effective hydrocarbon removal has been developed but not tested. An EPA report (EPA/540/5-90/004) for the 1-year investigation can be purchased through the National Technical Information Service, document No. PB 90-204 728/AS. A summary (EPA/540/S5-90/004) is also available.

6.2 ELECTROKINETICS INC.

Trade Name: Electro-Klean Electrokinetic Soil Processing

TECHNOLOGY DESCRIPTION:

The Electro-Klean electrokinetic soil process separates and extracts heavy metals and organic contaminants from soils. Electro-Klean can be applied in situ or ex situ, and uses direct currents with electrodes placed on each side of the contaminated soil mass. Conditioning fluids such as suitable acids may be used for electrode (cathode) depolarization to enhance the process. Conditioning pore fluids may be added or circulated at the electrodes to control process electrochemistry. Contaminants are electroplated on the electrodes or separated in a post-treatment unit. An acid front migrates towards the negative electrode (cathode) and contaminants are extracted through electrosmosis (EO) and electromigration (EM). The concurrent mobility of

the ions and pore fluid decontaminates the soil mass. The EO and EM supplement or replace conventional pump-and-treat technologies. Bench-scale results show that the process works in both unsaturated and saturated soils. Pore fluid flow moves from the positive electrodes (anodes) to the cathodes under the effect of the EO and EM forces. Electrode selection is important, since many metal or carbon anodes will rapidly dissolve from attack of strong oxidants.

WASTE APPLICABILITY:

Electro-Klean extracts heavy metals, radio-nuclides, and other inorganic contaminants below their solubility limit. Bench-scale tests have removed arsenic, benzene, cadmium, chromium, copper, ethylbenzene, lead, nickel, phenol, trichloroethene, toluene, xylene, and zinc from soils. Bench-scale studies under the SITE Program demonstrated the feasibility of removing uranium and thorium from kaolinite. Limited pilot-scale field tests resulted in zinc and arsenic removal from clays and saturated and unsaturated sandy clay deposits. Lead and copper were also removed from dredged sediments. Treatment efficiency depended on the specific chemicals, their concentrations, and the buffering capacity of the soil. The technique proved 85 to 95 percent efficient when removing phenol at concentrations of 500 parts per million. In addition, the removal efficiency for lead, chromium, cadmium, and uranium at levels up to 2,000 micrograms per gram ($\mu\text{g/g}$), ranged between 75 and 95 percent.

STATUS:

Bench-scale laboratory studies investigating heavy metal, radionuclide, and organic contaminant removal are complete, and radionuclide removal studies are complete under the SITE Emerging Technology Program. A pilot-scale laboratory study investigating removal of 2,000 g/g lead loaded onto kaolinite was completed in May 1993. Removal efficiencies of 90 to 95 percent were obtained. The electrodes were placed 3 feet apart in a 2-ton kaolinite specimen for 4 months, at an energy cost of about \$15 per ton. The results of a second pilot-scale laboratory study using 5000 g/g of lead adsorbed on kaolinite showed similar efficiency results as the earlier study. Bench-scale treatability studies and process enhancement schemes using conditioning fluids continue. Ongoing pilot-scale studies and a field study demonstrating lead removal from a military firing range will be conducted during 1994 and 1995; a new electrical separation process of extractive electrolysis will be pilot-tested for removal of multiple heavy metals. Based on results from the Emerging Technology Program, the Electro-Klean soil process was invited to participate in the SITE Demonstration Program. The field demonstration site is located at the southern side of the small arms Firing Range 24A at Fort Polk, Louisiana. The contaminant of interest is lead and the remediation area is approximately 20 by 60 feet, with a remediation depth of 3 feet. The adsorption of surface lead on the sandy clayey soil has been determined to be between 1,000 and 5,000ppm. The project is scheduled to run through spring 1996.

6.3 IT CORPORATION

(Chelation/electrodeposition of toxic metals)

TECHNOLOGY DESCRIPTION:

IT Corporation has conducted laboratory-scale research on an innovative process that removes heavy metals from contaminated soils and sludges by forming a soluble chelate. The metal and chelating compound are then separated from the soils and recovered. Soils are screened before the chelation step to remove large particles such as wood, metal scrap, and large rocks. The treatment employs two key steps: 1) using a water soluble chelating agent, such as ethylene-diaminetetraacetic acid, to bond with heavy metals and form a chelate; and 2) recovering the heavy metals from the chelate and regenerating the chelating agent in an electromembrane reactor (EMR). Dewatering is performed to separate the water soluble chelate that contains heavy metals from the solid phase. The resulting liquid is treated in an EMR, consisting of an electrolytic cell with a cation transfer membrane separating the cathode and anode chambers. This demonstration will establish appropriate conditions for removal of specific metals from various types of hazardous

BDM ENGINEERING SERVICES COMPANY

wastes. Previous research as focused primarily on the technology's applicability for treating and removing lead from contaminated soils and sludges. Limited work has also been conducted to determine the applicability for removing cadmium from soils and sludges.

WASTE APPLICABILITY:

The technology is potentially applicable for treating a wide variety of metal-contaminated hazardous wastes, including soils and sludges.

STATUS:

This technology was accepted to the SITE Emerging Technology Program in July 1994.

7.0 STEAM INJECTION TECHNOLOGIES

7.1 HUGHES ENVIRONMENTAL SYSTEMS, INC.

Trade Name: Steam Enhanced Recovery Process

TECHNOLOGY DESCRIPTION:

The Steam Enhanced Recovery Process (SERP) removes most volatile organic compounds (VOC) and semivolatile organic compounds (SVOC) from contaminated soils in situ both above and below the water table. The technology is applicable to the in situ remediation of contaminated soils below ground surface and below or around permanent structures. The process accelerates contaminant removal rates and can be effective in all soil types. Steam is forced through the soil by injection wells to thermally enhance the recovery process. Extraction wells are used for two purposes: to pump and treat groundwater, and to transport steam and vaporized contaminants to the surface. Recovered nonaqueous liquids are separated by gravity separation. Hydrocarbons are collected for recycling, and water is treated before being discharged to a storm drain or sewer. Vapors can be condensed and treated by any of several vapor treatment techniques (for example, thermal oxidation and catalytic oxidation). The technology uses readily available components such as extraction and monitoring wells, manifold piping, vapor and liquid separators, vacuum pumps, and gas emission control equipment.

WASTE APPLICABILITY:

The process can extract VOCs and SVOCs from contaminated soils and perched groundwater. Compounds suitable for treatment are hydrocarbons such as gasoline and diesel and jet fuel; solvents such as trichloroethene, trichloroethane, and dichlorobenzene; or a mixture of these compounds. After application of the process, subsurface conditions are excellent for biodegradation of residual contaminants. The process cannot be applied to contaminated soil very near the ground surface unless a cap exists. Denser-than-water compounds can be treated only in low concentrations unless a geologic barrier exists to prevent downward percolation.

STATUS:

The SITE demonstration of this technology began in August 1991 and was completed in September 1993. Soil at the site in Huntington Beach, California was contaminated by a large diesel fuel spill. The Demonstration Bulletin (EPA/540/HR-94/510) is available from EPA. The Innovative Technology Evaluation Report will be available from EPA in late 1994. For more information regarding this technology, see the Berkeley Environmental Restoration Center (Completed Projects), or Praxis Environmental Technologies, Inc., (Ongoing Projects) profiles in the Demonstration Program section. This technology is no longer available through this vendor. Contact the EPA Project Manager for further information.

DEMONSTRATION RESULTS:

Preliminary evaluation of the post-treatment data suggests the following conclusions: The geostatistical weighted average soil total petroleum hydrocarbons (TPH) concentration in the treatment area was 2,290 milligrams per kilogram (mg/kg). The 90 percent confidence interval for this average concentration is 996 mg/kg to 3,570 mg/kg, which shows that there is a high probability that the technology did not meet the cleanup criterion. Seven percent of soil samples had TPH concentrations in excess of 10,000 mg/kg. The geostatistical weighted average soil total recoverable petroleum hydrocarbons (TRPH) concentration was 1,680 mg/kg with a 90 percent confidence interval of 676 mg/kg to 2,680 mg/kg. Levels of benzene, toluene, ethylbenzene, and xylenes (BTEX) were below the detection limit (6 micrograms per kilogram) in post-treatment soil samples; BTEX was detected at low mg/kg levels in a few pretreatment soil samples. Analysis of triplicate samples showed marked variability in soil contaminant concentration over short distances. Analogous results for TPH and TRPH triplicate samples suggest that the contaminant concentration variability exists within the site soil matrix and is not the result of

analytical techniques. This variability is the reason that confidence intervals for the average concentrations are so large. The data suggests that lateral or downward migration of contaminants did not occur during treatment.

8.0 OTHER POTENTIALLY APPLICABLE TECHNOLOGIES

8.1 ASI ENVIRONMENTAL TECHNOLOGIES, INC./ DAMES & MOORE (Hydrolytic Terrestrial Dissipation)

TECHNOLOGY DESCRIPTION:

The Hydrolytic Terrestrial Dissipation (HTD) process was developed for use at the Chemairspray site in Palm Beach County, Florida. An estimated 11,500 cubic yards of surface soils at the site are contaminated with toxaphene (a chlorinated pesticide) and metal fungicides, primarily copper. After excavation, the HTD process mixes and grinds soils to uniformly distribute metal complexes and organic chemicals. During mixing, caustics are added to raise the soil pH to 8.0 or greater, although slower reactions should still occur at lower pHs. Soil moisture levels are maintained during mixing to prevent adsorption and fugitive dust. The prepared mixture is then distributed in a thin veneer (4 to 7 centimeters) over a soil bed and exposed to heat and ultraviolet (UV) light from the sun to facilitate dissipation. Sodium metabisulfite (a reducing agent), caustics, and moisture are added at intervals to maintain the reactions and ensure that metal catalysts are available to further the hydrolysis. As hydrolysis proceeds, toxaphene with 5 to 11 chlorine atoms per molecule transforms to lower molecular weights through dechlorination and other processes. UV light within the visible spectrum is also known to cleave the carbon-chloride bond as well as other chemical bonds. As lower weight toxaphene molecules occur at the surface of the soil mixture, the molecular structure should further degrade to still lower weight compounds. HTD uses metal-catalyzed alkaline hydrolysis reactions with a reducing agent to liberate chlorine ions from the toxaphene's molecular structure. Depending on numerous factors, including the nature of the contaminated media, liberated chlorine ions probably mineralize in the soil. HTD is a slowly occurring process that should degrade toxaphene to camphene (C₁₀H₁₆) or similar innocuous compounds, which ultimately break down to water and other carbon oxides (CO_x). Soils in the distribution bed are periodically sampled to evaluate any residual contamination. Also, the quality of underlying groundwater is monitored during operation. After treated soils meet established criteria, the land may be returned to beneficial use. One staging unit can treat about 5,000 to 6,000 cubic yards per year.

WASTE APPLICABILITY:

HTD is a process designed around the physical chemistry of the contaminant and its environment. Depending upon the site and contaminant, metal catalysts, reducing (or perhaps oxidizing) compounds, conditions of the process, and other parameters may be altered within the HTD design to provide effective treatment under a wider range of applications. HTD's current design can treat large amounts of soil contaminated by small amounts (less than 1 percent) of toxaphene and other pesticides. The physical chemistry of the target contaminants dictates modifications for other applications; however, the process should only be designed with sufficient time for reactions to occur. Although setup for HTD implementation may be reasonably inexpensive compared with other remedial programs, the process can require large amounts of land for its distribution bed. Of its potential applications, agricultural or other large land uses are currently preferable sites. HTD may also have applications when coupled with other passive technologies, such as bioremediation, to provide an integrated remedial activity.

STATUS:

The HTD process was accepted into the SITE Demonstration Program in spring 1991. A simulation tank has been constructed to evaluate hydrolysis under laboratory conditions. A quality control program validated laboratory results. Soil moisture may play a major role in releasing toxaphene from its bound state and allowing degradation. Treatability studies were conducted with soil moisture at about 50 percent, soil pH at 8.5, air temperature at 102 to 105 degrees Fahrenheit, and a UV wavelength of 356 nanometers (nm). Under simulated conditions, these studies also show that HTD methods slowly degrade organo-chlorine and other pesticides in

contaminated soils. Additional studies under similar conditions that include a reducing agent and slightly higher frequency UV light (256 nm), show that it is possible to enhance and accelerate toxaphene's degradation reactions.

8.2 CENTER FOR HAZARDOUS MATERIALS RESEARCH

(Smelting lead-containing waste)

TECHNOLOGY DESCRIPTION:

Secondary lead smelting is a proven technology that reclaims lead from lead-acid battery waste sites. The Center for Hazardous Materials Research (CHMR) and Exide Corporation (Exide) have demonstrated the use of secondary lead smelting to reclaim usable lead from various types of waste materials. Reclamation of lead from Superfund and other lead-containing sites is based on existing lead smelting procedures and basic pyrometallurgy. Waste material is first excavated from Superfund sites or collected from other sources. The waste is then preprocessed to reduce particle size and to remove rocks, soil, and other debris. Next, the waste is transported to the smelter. At the smelter, waste is fed to reverberatory or blast furnaces, depending on particle size or lead content. The two reverberatory furnaces normally treat lead from waste lead-acid batteries, as well as other lead-containing material. The furnaces are periodically tapped to remove slag, which contains 60 to 70 percent lead, and a soft pure lead product. The two blast furnaces treat slag generated from the reverberatory furnaces, as well as larger-sized lead-containing waste. These furnaces are tapped continuously for lead and tapped intermittently to remove slag, which is transported offsite for disposal. The reverberatory and blast furnace combination at Exide can reclaim lead from batteries and waste with greater than 99 percent efficiency.

WASTE APPLICABILITY:

The process has been demonstrated to reclaim lead from a variety of solid materials, including rubber battery case material, lead dross, iron shot abrasive blasting material, and wood from demolition of houses coated with lead paint. The technology is applicable to solid wastes containing more than 2 percent lead, provided that they do not contain excessive amounts of calcium, silica, aluminum, or other similar constituents. Explosive and flammable liquids cannot be processed in the furnace. As tested, this technology is not applicable to soil remediation.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1991. Field work for the project was completed in February 1993. Reports are available for many of the demonstrations, and CHMR is completing the final technology report. An article about the technology will be published by the Journal of Hazardous Materials in fall 1994. The process was tested at three Superfund sites. Materials obtained from two additional sites were also used for these tests. Results from the Emerging Technology Program, presented in the table below, show that the process is applicable to waste materials at each site and economically feasible for all but the demolition material from the Laurel House site.

Specific technical problems encountered included: 1) loss of furnace production due to material buildup within the furnaces, 2) breakdowns in the feed system due to mechanical overloads, and 3) increased oxygen demands inside the furnaces. All of these problems were solved by adjusting material feed rates or furnace parameters.

Based on these tests, CHMR has concluded that secondary lead smelting is an economical method of reclaiming lead from lead-containing waste material collected at Superfund sites and other sources.

8.3 FILTER FLOW TECHNOLOGY, INC.

(Heavy metals and radionuclide polishing filter)

TECHNOLOGY DESCRIPTION:

The colloid polishing filter method (CPFM) uses an inorganic, oxide-based compound of granular pellets (Filter Flow 1000) to remove colloidal and ionic form heavy metals and nontritium radionuclides from water. Contaminants are removed through a combination of sorption, chemical complexing, and filtration. The CPFM effectively removes inorganic metallic pollutants from groundwater or wastewater, and can be used independently or subsequent to flocculation and bulk solids removal. The primary treatment and CPFM process involves five basic steps. If necessary, contaminated water is first pumped to an influent mixing tank for chemical preconditioning (pH adjustment or sodium sulfide addition) to induce formation of colloidal forms of pollutants. Second, suspended solids are removed by an incline plate mini-clarifier or filter. Next, microparticles are removed using overflow water. The low solids then pass through to the colloid filter press units, where heavy metals and radionuclides are removed by the sorption, chemical complexing, and filtration effects of Filter Flow 1000. Finally, the pH of treated water exiting the colloid filters is adjusted prior to discharge. Following treatment, sludge in the miniclarifier is dewatered. The filter packs are dewatered with compressed air to form a cake containing 60 to 70 percent solids. These two solid wastes may be combined for disposal. Optional single-use, disposable, and reusable bed material designs have been developed, with emphasis on easy, safe handling and removal of the spent filter pack material. Both batch (up to 10,000 gallons per run) and continuous (5 to 100 gallons per minute) treatment systems have been designed for application in both mobile field equipment and fixed installations.

WASTE APPLICABILITY:

The CPFM efficiently removes heavy metals and nontritium radionuclides from water to parts per million or parts per billion levels. This simple methodology can be used separately to treat water with low total suspended solids; in a treatment train downstream from other technologies such as soil washing, organic oxidation, or as a conventional wastewater treatment that uses flocculation and solids removal. The CPFM's major advantage is high performance and lower cost to treat a wide range of inorganic metallic pollutants in water, including monovalent and divalent forms, multivalent and high valence forms existing as colloids, and ionic, chelated, and complexed forms. The same equipment can treat water at different sites, but the preconditioning chemistry and pH must be optimized for each site from bench and field test results.

STATUS:

This technology was accepted into the SITE Demonstration Program in July 1991. EPA and the U.S. Department of Energy (DOE) co-sponsored the technology evaluation. The SITE demonstration occurred at DOE's Rocky Flats Plant (RFP), Denver, Colorado, in September 1993 under a cooperative understanding between EPA and DOE. The Demonstration Bulletin (EPA/540/MR-94/501) and Capsule Report (EPA/540/R-94/501a) are available from EPA.

DEMONSTRATION RESULTS:

The CPFM treated about 10,000 gallons of water that contained about 100 milligrams per liter of uranium and 100 picoCuries per liter of gross alpha-contaminated groundwater. The demonstration was comprised of three tests. The first test consisted of three runs of 4 hours each, treating about 5 gallons per minute (gpm). For the second test, also run for 4 hours at 5 gpm, the influent water was pre-treated with sodium sulfide. The third test was a 15-hour run designed to determine the amount of contamination each filter pack could treat. The CPFM system removed up to 95 percent uranium and 94 percent gross alpha contamination. However, due to the significant variation in removal efficiencies between runs, average removal efficiencies were significantly less: 80 percent for uranium, and 72 percent for gross alpha. Though removal is largely attributable to the colloid filter pack, uranium was significantly removed in runs 1 and 4

before the colloid filter unit. Significant gross alpha was also removed before colloid filter treatment in runs 1 and 3. At less than the maximum removal efficiency, effluent from the CPM system did not meet the extremely strict Colorado Water Quality Control Commission standards for discharge of waters from RFP.

8.4 RISK REDUCTION ENGINEERING LABORATORY and USDA FOREST PRODUCTS LABORATORY

(Fungal treatment technology)

TECHNOLOGY DESCRIPTION:

This biological treatment system uses white rot fungi to treat soils in situ. These lignin-degrading fungi bioremediate certain organic contaminants. Organic materials inoculated with the fungi are mechanically mixed into the contaminated soil. Using enzymes normally produced for wood degradation as well as other enzyme systems, the fungi break down soil contaminants. Because this technology uses a living organism, the greatest degree of success occurs with optimal growing conditions. Moisture control is necessary, and temperature and aeration may also be controlled. Organic nutrients such as peat may be added to soils deficient in organic carbon.

WASTE APPLICABILITY:

This biological treatment system was initially developed to treat soil contaminated with chemicals found in the wood preserving industry. These contaminants include chlorinated organics and polynuclear aromatic hydrocarbons (PAH). The system may remediate different contaminants and combinations of contaminants with varying degrees of success. In particular, the SITE Demonstration Program evaluated how well white rot fungi degrades pentachlorophenol (PCP) in combination with creosote PAHs.

STATUS:

This biological treatment system was accepted into the SITE Demonstration Program in April 1991. In September 1991, a treatability study was conducted at the Brookhaven Wood Preserving site in Brookhaven, Mississippi. Site soils were contaminated with 700 parts per million (ppm) PCP and 4,000 ppm PAH. Study results showed that one lignin-degrading fungus removed 89 percent of PCP and 70 percent of total PAHs during a 2-month period. A full-scale demonstration of this fungus was completed in November 1992 to obtain economic data. The Demonstration Bulletin (EPA/540/MR-93/505) is available from EPA. The full-scale project involved a 1-acre plot of contaminated soil and two smaller control plots. The soil was inoculated with *Phanaerochaete sordida*, a species of white rot fungus. No woodchips or other bulking agents were added to the prepared soil. Field activities included tilling and watering all plots. No nutrients were added. Air emissions data showed no significant hazards to field technicians due to soil tilling activities. Contaminated soil, underlying sand, and leachate had no significant contamination. Initial results showed a 70 percent reduction in contaminants, both in the plot containing the fungal treatment and in the plot containing a nonfungal, organic amendment. Unidentified, indigenous fungal species may have significantly reduced contaminants in the nonfungal plot. About 13 percent of contamination was removed from the nonamended (soil-only) control plot.

DEMONSTRATION RESULTS:

Some key findings from the demonstration are as follows: Levels of PCP and the target PAHs found in the underlying sand layer and the leachate from each of the plots were insignificant, indicating low leachability and loss of these contaminants due to periodic irrigation of the soil and heavy rainfall. Levels of PCP, the target PAHs, and dioxins in the active air samples collected during the soil tilling events were insignificant, indicating a very low potential for airborne contaminant transport.

APPENDIX I

Summary Table of Vendors and their Remediation Technology

BDM ENGINEERING SERVICES COMPANY

| Vendor | Address | Contact/Phone | Technology Description | Development Status |
|--|--|--|--------------------------------|--------------------|
| Accel Industrial and Mineral Processes Ltd. | Level 5 160 Queen Street Melbourne 3000 Australia | Ian Desborough Ennis 61-3-9602-2755 | Acid Extraction | full-scale |
| Australian Defence Industries Ltd (ADIL) | Level 22, Plaza II, Cnr Grosvenor & Grafton Sts, Bondi Junction, Sydney, NSW, Aust. | Ken Harris 61-2-365-9300 | Soil Washing / Acid Extraction | full-scale |
| Advanced Remediation Mixing | 711 Oxley St Kenner, LA 70062 | Sam V. Pizzitola, III (504) 461-0466 | Stabilization | full-scale |
| AEA Technology | Culham Abingdon, Oxfordshire OX14 3DB, England | Peter Allan Wood (123) 546-3194 | Soil Washing | pilot-scale |
| Alternative Remedial Technologies, Inc | 14497 North Dale Mabry Hwy. Tampa, FL 33618 | Michael Mann (813) 264-3506 | Soil Washing | full-scale |
| Andco Environmental Processes, Inc. | 595 Commerce Drive Buffalo, NY 14228-2380 | Michael Laschinger (716) 691-2100 | Stabilization | pilot-scale |
| ASI Environmental Science Inc., / HydroScience, Inc. | P.O. Box 2856 Brandon, FL 33509-2856 | Stoddard Pickrell, Jr. (813) 653-3376 | Other | pilot-scale |
| Battelle Memorial Institute | 505 King Avenue Columbus, OH 43201 | Satya Chauhan (614) 424-4812 | Electro-Technologies | pilot-scale |
| BenCHEM | 803 S. Negley Ave., Suite 1 Pittsburgh, PA 15232 | Robert Bender (412) 361-1426 | Soil Washing | full-scale |
| Bergmann USA | 1550 Airport Rd. Gallatin, TN 37066 | Richard Traver (615) 452-5500 | Soil Washing | full-scale |
| Best Sulfur Products | 5427 E. Central Ave. Fresno, CA 93725 | Roy Hardison (800) 447-5826 | Stabilization | full-scale |

BDM ENGINEERING SERVICES COMPANY

| Vendor | Address | Contact/Phone | Technology Description | Development Status |
|--|--|---------------------------------------|------------------------|--------------------|
| BioGenesis Enterprises | 10626 Beechnut Ct. Fairfax Station, VA 22309 | Charles Wilde (703) 250-3442 | Soil Washing | full-scale |
| BioTrol, Inc | 10300 Valley View Rd. Eden Prairie, MN 55344 | Sandy Clifford (612) 942-8032 | Soil Washing | pilot-scale |
| Brice Environmental Services Corp. (BESCOP) | P. O. Box 73520 Fairbanks, AK 99707 | Craig Jones (907) 452-2512 | Soil Washing | full-scale |
| Canonie Environmental Services Corp. | 94 Inverness Terrace East, Suite 100 Englewood, CO 80112 | Alistair Montgomery (303) 790-1747 | Soil Washing | full-scale |
| Center for Hazardous Materials Research | 320 William Pitt Way Pittsburgh, PA 15238 | Stephen Paff (412) 826-5320 | Acid Extraction | pilot-scale |
| COGNIS, Inc. | 2330 Circadian Way Santa Rosa, CA 95407 | Eric Klein (707) 576-6239 | Acid Extraction | full-scale |
| ContraCon Northwest | 4519 131st Place, SW Mukilteo, WA 98275 | Thomas C. Leggiere (206) 787-9600 | Stabilization | full-scale |
| Corpex Technologies, Inc. | 5400 S. Miami Blvd Morrisville, NC 27560 | John K. Pirotte (919) 941-0847 | Chemical Treatment | bench-scale |
| Davy International - Environmental Div. | Ashmore House Richardson Road Stockton-on Tees Cleveland TS18 3RE United Kingdom | George Rowden (164) 260-2221 | Chemical treatment | pilot-scale |
| Delphi Research, Inc. | 701 Haines Avenue, NW Albuquerque, NM 87102 | Jeffrey Campbell (505) 243-3111 | Chemical Treatment | pilot-scale |
| Earth Treatment Technologies, Inc. | Dutton Mill Industrial Park 396 Turner Way Aston, PA 19014 | Troy Duguay (610) 497-6729 | Acid Extraction | full-scale |

BDM ENGINEERING SERVICES COMPANY

| Vendor | Address | Contact/Phone | Technology Description | Development Status |
|---|--|-------------------------------------|------------------------|--------------------|
| Earth Decontaminators, Inc. (EDI) | 2803 Barranca Parkway Irvine, CA 92714 | Luis Pommier (714) 262-2292 | Acid Extraction | full-scale |
| Electrokinetics Inc. | Louisiana Business and Technology Center, Suite B-155 South Stadium Drive Baton Rouge, LA 70803 | Akram Alshawabkeh (504) 388-3992 | Electrokinetics | full-scale |
| ENSR Consulting and Engineering & NuKem Development | 3000 Richmond Ave. Houston, TX 77098 | Saeed Darian (713) 520-9900 | Soil Washing | full-scale |
| ETUS, Inc. | 1511 Kastner Place Building #1 Technology Drive Sanford, FL 32771 | Richard Dunkel (407) 321-7910 | Chemical Treatment | full-scale |
| Filter Flow Technology, Inc. | 122 Texas Avenue League City, TX 77573 | Tod Johnson (713) 332-3438 | Other | full-scale |
| GEOCHEM Division of Terra Vac | 12596 W. Bayaud Ave., Suite 205 Lakewood, CO 80228 | Jim Rouse (303) 988-8902 | Soil Washing | bench-scale |
| Geo-Con, Inc. | 4075 Monroeville Blvd. Corporate One, Building II, Suite 400 Monroeville, PA 15146 | Linda Ward (412) 856-7700 | Stabilization | full-scale |
| Geocycle Environment, Inc | 2630 Blv. Industrial Chambly, Quebec J3L-4V2, Canada | Pierre Geoffroy (514) 447-5252 | Soil Washing | pilot-scale |
| Hughes & the U.S. EPA Risk Reduction Engineering Laboratory | 26 West Martin Luther King Drive Cincinnati, OH 45268 | Paul dePercin (513) 569-7797 | Steam Extraction | pilot-scale |

BDM ENGINEERING SERVICES COMPANY

| Vendor | Address | Contact/Phone | Technology Description | Development Status |
|--|---|------------------------------------|----------------------------------|--------------------|
| Hydriplex, Inc. | 14730 Sandy Creek Drive Houston, TX 77070 | John S. Crowley (713) 370-2778 | Soil Washing | full-scale |
| Integrated Chemistries, Inc. | 1970 Oakcrest Ave. Suite 215 St. Paul, MN 55113 | Cathy Iverson (612) 636-2380 | Chemical Treatment | full-scale |
| Intera | | | | |
| IT Corporation | 312 Directors Drive Knoxville, TN 37923 | Edward Alperin (615) 690-3211 | Acid Extraction & Electro- Techs | pilot-scale |
| Kinit Enterprises | 6363 NW 6th Way Ft. Lauderdale, FL 33309 | Claus D. Tonn (305) 776-4829 | Soil Washing | full-scale |
| Lewis Environmental Services, Inc. | R.J. Casey Industrial Park Preble and Columbus Streets Pittsburgh, PA 15233 | Tom Lewis III (412) 322-8100 | Acid Extraction | full-scale |
| Lockheed Corp. | 980 Kelly Johnson Dr. Las Vegas, NV 89119 | Ron May (702) 897-3313 | Acid Extraction | full-scale |
| Lockheed Corp. | 980 Kelly Johnson Dr. Las Vegas, NV 89119 | Ron May (702) 897-3313 | Soil Washing | full-scale |
| Marcor Management, Inc | P. O. Box 1043 Hunt Valley, MD 21030 | Kevin P. Walls (410) 785-0001 | Soil Washing | full-scale |
| Metcalf & Eddy | 30 Harvard Mill Square Wakefield, MA 01880 | Douglas Shattuck (617) 224-6247 | Soil Washing | full-scale |
| Montana College of Mineral Science & Technology | West Park Street Butte, MT 57901 | Theodore Jordan (406) 496-4112 | Soil Washing | full-scale |
| Monterverde Inc. | 6501 Americas Parkway NE, Suite 200 Albuquerque, NM 87110 | Rupert Spivey (505) 875-0420 | Stabilization | full-scale |
| Environmental Services & Technologies | | | | |
| New Jersey Institute of Technology Dept. of Chemical Engineering | Newark, NJ 07102 | Itzhak Gotlieb (201) 596-5862 | Soil Washing | full-scale |

BDM ENGINEERING SERVICES COMPANY

| Vendor | Address | Contact/Phone | Technology Description | Development Status |
|--|---|--|------------------------------------|----------------------|
| On-Site Technologies | 1715 S. Bascom Ave. Campbell, CA 95008 | Masood Ghassemi (408) 371-4810 | Soil Washing | full-scale |
| Pittsburgh Mineral & Environmental Technology, Inc. | 700 Fifth Avenue New Brighton, PA 15066 | Casimir J. Koshinski (412) 843-5353 | Soil Washing | full-scale |
| PSI Technologies A Division of Physical Sciences Inc. | 20 New England Business Center Andover, MA 01810 | Joseph Morency (508) 689-0003 | Stabilization | pilot-scale |
| RMT, Inc | 744 Heartland Trail Madison, WI 53717 | Christopher Rehmann (608) 831-4444 | Stabilization | full-scale |
| Risk Reduction Engineering Laboratory | 11499 Chester Rd. Cincinnati, OH 45246 | Michael Taylor (513) 782-4700 | Soil Washing & Other | pilot- to full-scale |
| Scientific Ecology Group (SEG) | 1501 Ardmore Blvd. Pittsburgh, PA 15221 | Patrick Keegan (412) 247-6255 | Soil Washing | full-scale |
| Sevenson Environmental Services, Inc. | 9245 Calumet Ave., Suite 101 Munster, IN 46321 | Charles McPheeters (812) 988-9930 | Chemical Treatment | full-scale |
| Smith Environmental Technologies, Corp. | 108 St. Anthony St P. O. Box 1784 Mobile, AL 36633 | Ken Lovell (334) 433-3981 | Soil Washing | full-scale |
| Soil Technology, Inc | 7865 NE Day Road West Bainbridge Island, WA 98110 | Richard Sheets (206) 842-8977 | Soil Washing | bench-scale |
| SOLUCORP Industries, Ltd. | 520 Victor Street Baddle Brook, NJ 07663 | Noel Spindler (201) 368-7902 | Chemical Treatment & Stabilization | full-scale |
| STC Omega, Inc. | 7655 East Gelding Drive, Suite B-2 Scottsdale, AZ 85260 | Stephen Pelger (602) 948-7100 | Stabilization | full-scale |
| Technology Scientific, Ltd. | 152 Ranch Estates Dr. N.W. Calgary, Alta. T3G 1K4 Canada | Richard Petela (403) 239-1239 | Soil Washing | bench-scale |
| TechTran Environmental, Inc. | 9800 Northwest Freeway, Suite 302 Houston, TX 77092 | E.B. (Ted) Daniels (713) 680-8833 | Stabilization | pilot-scale |

BDM ENGINEERING SERVICES COMPANY

| Vendor | Address | Contact/Phone | Technology Description | Development Status |
|--|--|--------------------------------------|------------------------|--------------------|
| Terra-Kleen Response Group, Inc. | 7321 North Hammond Avenue Oklahoma City, OK 73132 | Alan Cash (405) 728-0001 | Solvent Extraction | full-scale |
| The Toronto Harbour Commissioners | 60 Harbour Street Toronto, Ontario, Canada M5J 1B7 | Carol Moore (416) 863-2071 | Soil Washing | full-scale |
| Tuboscope Environmental Services (TVIES) | 2835 Holmes Rd. Houston, TX 77501 | Myron Kuhlman (713) 799-5289 | Soil Washing | full-scale |
| University of Houston | Dept. of Civil and Environmental Engineering University of Houston Houston, TX 77204 | Dennis Clifford (713) 743-4266 | Solvent Extraction | pilot-scale |
| Viking Industries | 1015 Old Lascassas Road Murfreesboro, TN 37130 | Don T. Pearson (615) 890-1018 | Chemical Treatment | pilot-scale |
| Warren Springs Laboratory | Gunnels Wood Rd. Stevenage, Herts SG12BX England | Peter Allan Wood 44-438-741-122 | Soil Washing | bench-scale |
| WASTECH, Inc. | P.O. Box 4638 1021 D Alvin Weinberg Drive Oak Ridge, TN 37831 | Benjamin Peacock (615) 483-6515 | Stabilization | pilot-scale |
| West Central Environmental Consultants | 14 Green River Road P.O. Box 594 Morris, MN 56267 | Galen Weisenburger (800) 422-8356 | Stabilization | full-scale |
| Western Environmental Science & Technology | 45133 Country Road 32B Davis, CA 95616 | Troy G. Turpen (916) 753-9500 | Soil Washing | full-scale |
| Westinghouse Remediation Services, Inc. | 675 Park North Blvd. Building F, Suite 100 Clarkston, GA 30021 | William Norton (404) 299-4736 | Soil Washing | full-scale |

APPENDIX II

Summary Table of Vendors Responding Without a Specific Remediation Technology

BDM ENGINEERING SERVICES COMPANY

| VENDOR | ADDRESS | CONTACT |
|---|--|---------------------------------------|
| Abatement Services, Inc. | 3202 West 70th Shreveport, LA 71108 | E. H. Turner, Jr. (318) 686-7577 |
| Advanced Recovery Systems, Inc. | 1219 Banner Hill Rd. Erwin, TN 37650 | Steve Schutt (615) 743-6186 |
| ARCTECH, Inc. | 14100 Park Meadow Drive Chantilly, VA 22021 | Daman Wallia (703) 222-0280 |
| ATC Environmental | 5031 S. Ulster St., Suite 100 Denver, CO 80237 | Carhy B. Ganley (303) 793-9939 |
| Bell Environmental Corp. | 705 N. Bowser, Suite 112 Richardson, TX 75081 | Robert Walker (214) 664-9214 |
| Chemical Separation Technology, Inc. | 3015 Washington Road McMurray, PA 15317 | James G. Werner (412) 942-0679 |
| Consolidated Environmental Services, Inc. | 15851 Dallas Parkway, Suite 720 Dallas, TX 75248 | Mark Risk (214) 770-7965 |
| Denver Mineral Engineers, Inc. | 8122 South Park Lane, Suite 110 Littleton, CO 80120 | Bill Lemmel (303) 932-6280 |
| DuPont Environmental Remediation Services | Barley Mill Plaza 27 P. O. Box 80027 Wilmington, DE 19880 | Charles Horton (302) 992-2452 |
| Eagle Construction & Environmental Services, Inc. | P. O. Box 872 Eastland, TX 76448 | Johnny V. Cagle (817) 629-1718 |
| EPS Engineering Services, Inc. | 1400 Easton Drive, Suite 105 Bakersfield, CA 93309 | Partick Mbaba (805) 322-6675 |
| Inmetco | P. O. Box 720 245 Portersville Rd Ellwood City, PA 16117 | (412) 758-5515 |
| In Situ Remediation Inc. | P. O. Box 90 Dover, ID 83825 | Heikki Kuster (208) 263-7327 |
| Kencon Environmental, Inc. | 2311 Rt. 70 W. Professional Bldg. One Cherry Point, NJ 08002 | Dr. Kargbo (609) 665-4575 |
| NCI, Inc | Hillsboro, NM 8804x | (505) 895-5631 |
| NHD, Inc | RR #4, Box 4452 Drums, PA 18222 | Kenneth J. Skuba (717) 788-5048 |
| OHM Remediation Services Corp | 1990 N. California Blvd., Ste 400 Walnut Creek, CA. 94596 | Dwight Gemar (510) 256-6100 |
| Philip Environmental Services Corp. | 210 West Sand Road P. O. Box 230 Columbia, IL 62236 | Donald L. Baum, Jr. (616) 281-7173 |
| Precision Fabricating & Cleaning | 505 Canaveral Groves Blvd. Cocoa, FL 32926 | Jean C. Shaw (407) 635-2000 |
| Roberts & Schaefer Company | 5225 Wiley Post Wasy, Suite 300 Salt Lake City, UT 84116 | Burk Adams (801) 364-0900 |
| Roy F. Weston, Inc. | 1 Weston Way West Chester, PA 19380 | Sharon M. Fry (610) 701-7365 |
| Signal Environmental Services, Inc. | 900 Manufactures Rd. P. O. Box 4270 Chattanooga, TN 37405 | Cynthia Raines (423) 265-9551 |

BDM ENGINEERING SERVICES COMPANY

| VENDOR | ADDRESS | CONTACT |
|------------------------------|--|-------------------------------|
| Univ. of Missouri - Columbia | Dept. of Civil Engineering E2509 Engineering Bldg. East Columbia, MO 65211 | Mary McCush (314) 882-6084 |
| W. R. Rand, Inc | Corporate Box 60 Gillette, NJ 07933 | J. Rand (908) 766-7422 |

APPENDIX III

**Table Listing European Technology Vendors
with Technology Status Summary**

BDM ENGINEERING SERVICES COMPANY

| VENDOR | Highest Scale of Operation | Year Program Began | Range of Particle Size Treated | Contaminants Extracted From Soil | Extraction Agent(s) | Efficiency of Contaminant Removal |
|------------------------------|--------------------------------|--------------------|--|---|---|-----------------------------------|
| Harbauer | Commercial 15-20 tons/hr | 1986 | 15 μ m - 5mm Pretreatment; Coarse screens, electromagnet blade washer | Limited Heavy Metal Removal Experience | Hydraulically produced oscillation / vibration Surfactants Acid / Base | N/A |
| HWZ Bodemsangering BV | Commercial 20 - 25 tons/hr | 1984 | <10mm and >63 μ m | Cyanide, Chlorinated HC, some heavy metals, PNA | Sodium Hydroxide to adjust pH; Surfactants | Hms 75%; residual 75-125 ppm |
| Heijman Milieutechniek BV | Pilot-scale 10 - 15 tons/hr | 1985 | <10mm and no more than 30% <63 μ m | Cyanide, heavy metals, mineral oil | Proprietary extraction agents. Hydrogen Peroxide added to react with extracted CN to form CO ₂ and NH ₃ | Hms 70%; Residual <200 ppm |
| Heidemij Froth Flotation | Full-Scale | N/A | <4 mm and no more than 20% <50 μ m | Cyanide, heavy metals, oil, chlorinated Hcs, toluene, benzene, pesticides, etc. | Proprietary Surfactants and other proprietary chemicals | Hms >90%; Residual >150 ppm |

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